Experimental Validation of Human and FlexPLI FE Models

Action List Item 1. b)
Assessment of biofidelity

5th IG GTR9-PH2 Meeting
6-7/December/2012

Japan Automobile Standards Internationalization Center (JASIC)

IWG Questions from NHTSA

GTR9-5-12

GTR9-4-19

Overview of NHTSA Pedestrian Activities

Sept. 17-18, 2012

GTR9-4-19

FlexPLI: Biofidelity

Previous	Current	IWG Question
• Reviewed literature, FlexTEG/IWG Phase 2 studies. • We agree that FlexPLI covers more injuries than TRL legform.	• We are not currently planning any biomechanical studies to directly compare Flex to human response	• What is status of JASIC/JARI CAE correlation study evaluating upper body mass effects in high bumper impacts? Experimental validation of model results would be beneficial.

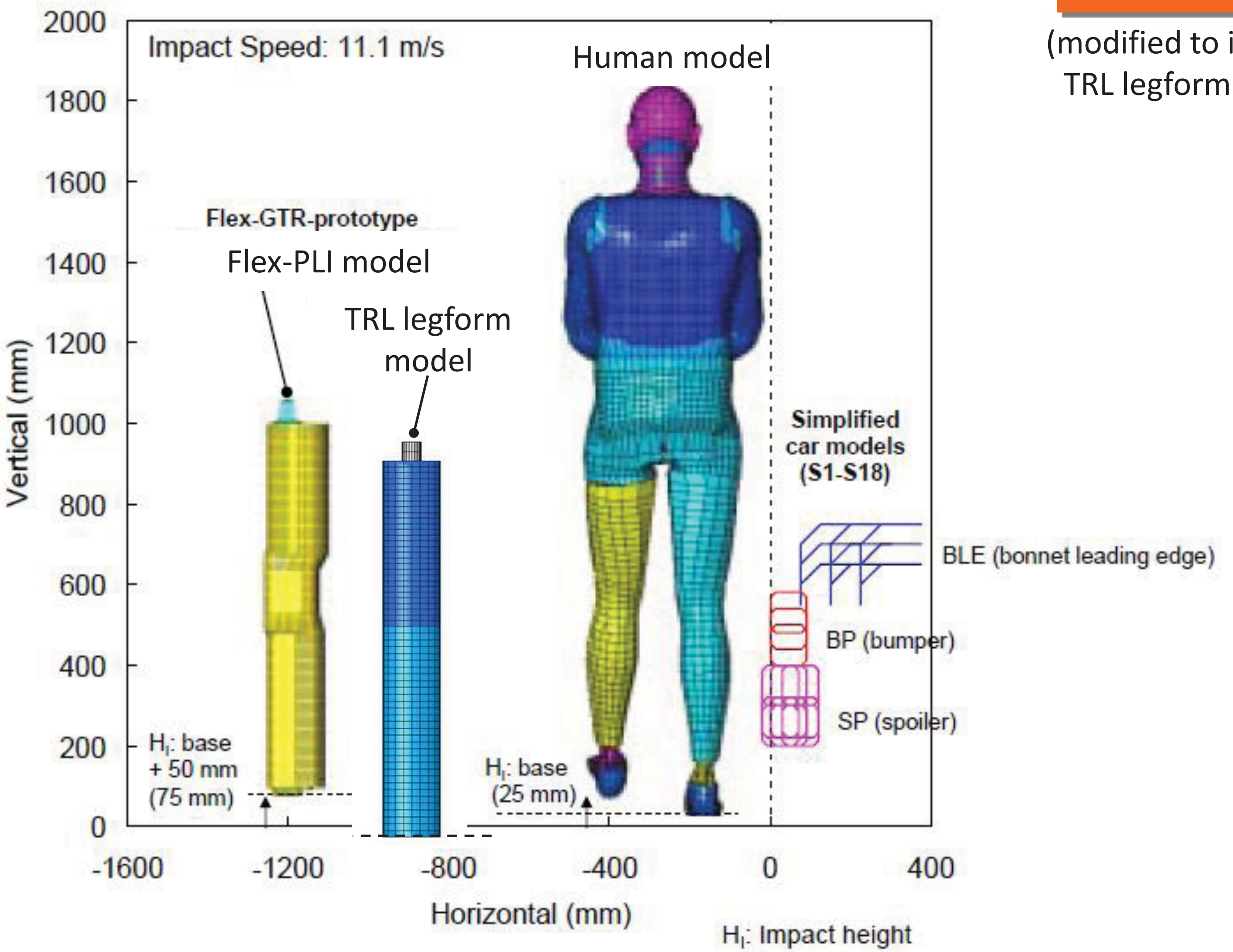
Reference : National Highway Traffic Safety Administration (NHTSA), *Overview of NHTSA Pedestrian Activities*, 4th IG GTR9-PH2 Meeting Document, GTR9-4-19 (2012)

Correlation of Assembly Impact Responses

CAE Correlation Study

TEG-096

(modified to include TRL legform)



Reference : Japan Automobile Standards Internationalization Center (JASIC), *Technical Discussion - Biofidelity*, 1st IG GTR9-PH2 Meeting Document, GTR9-1-05r1 (2011)

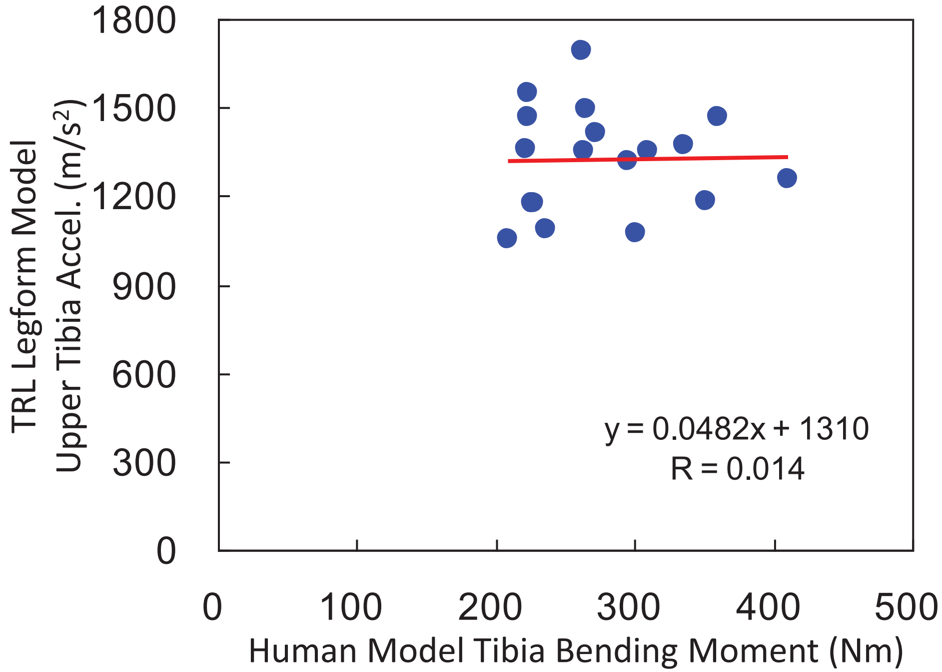
Correlation of Assembly Impact Responses

Correlation of Tibia Injury Measures

TEG-096

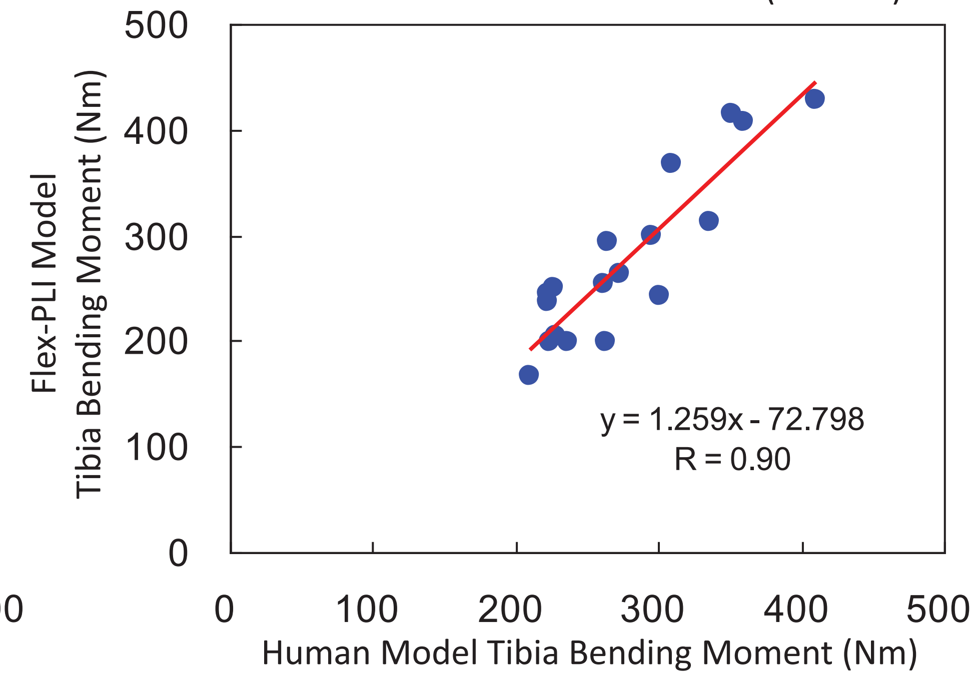
(Flex-PLI)

TRL Legform



Konosu et al. (2009)

Flex-PLI



- **No correlation between TRL legform upper tibia acceleration and human tibia bending moment**
- **Good correlation between Flex-PLI and human tibia bending moment**

Reference : Japan Automobile Standards Internationalization Center (JASIC), *Technical Discussion - Biofidelity*, 1st IG GTR9-PH2 Meeting Document, GTR9-1-05r1 (2011)

Correlation of Assembly Impact Responses

Correlation of MCL Injury Measures

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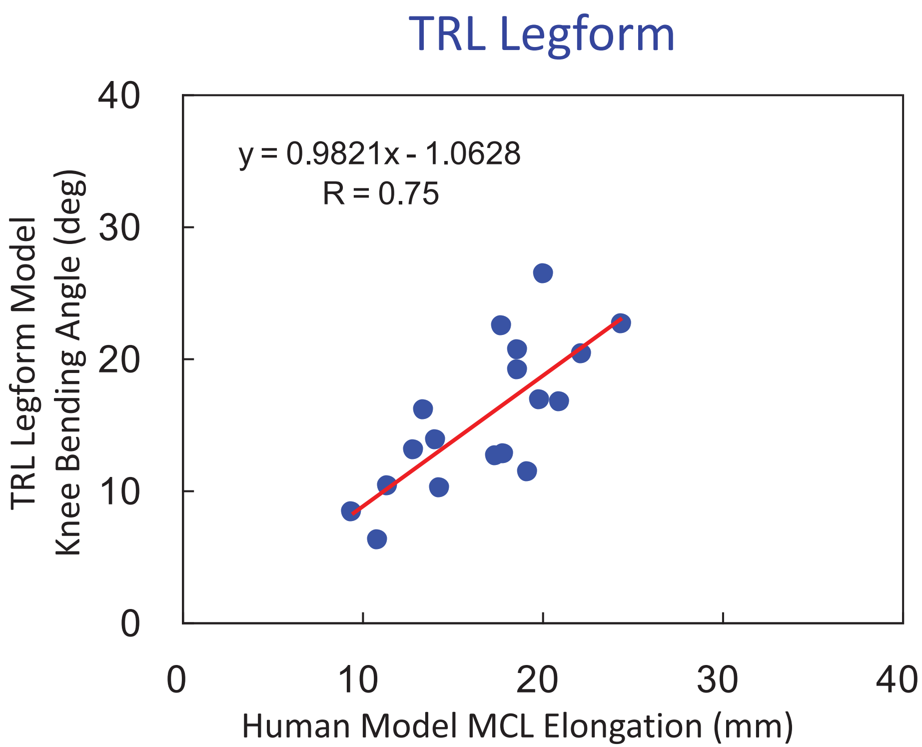
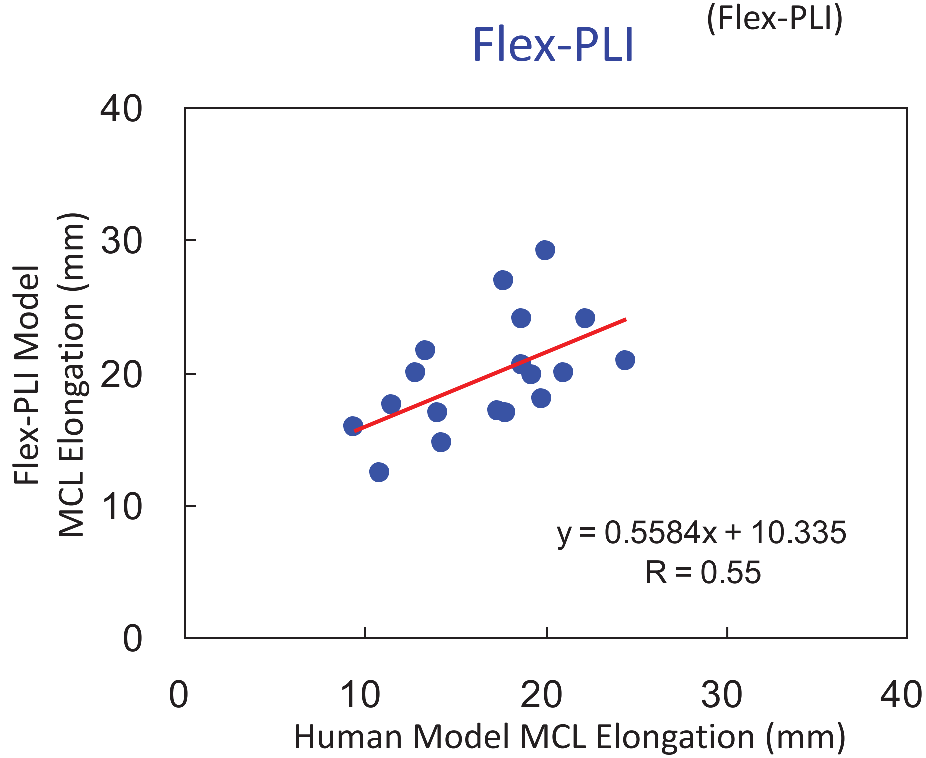
(Flex-PLI)



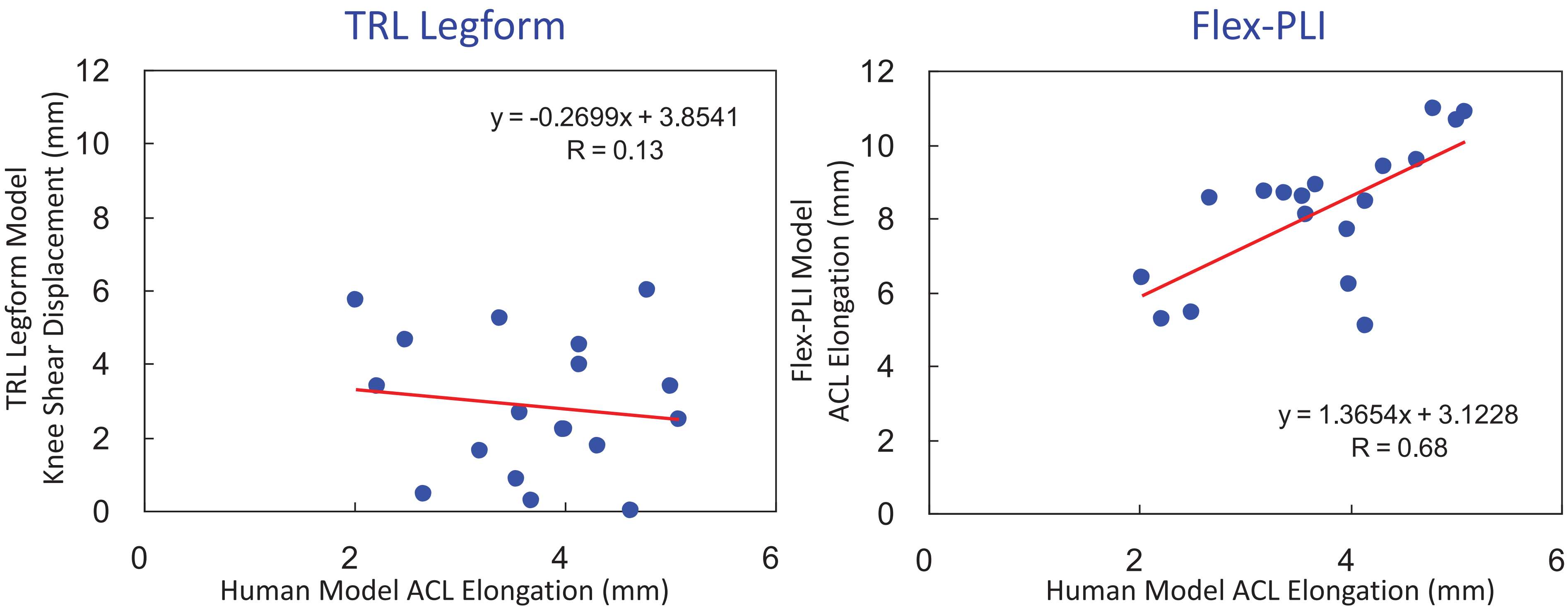


Both TRL legform knee bending angle and Flex-PLI MCL elongation show good correlation with human MCL elongation

Reference : Japan Automobile Standards Internationalization Center (JASIC), *Technical Discussion - Biofidelity*, 1st IG GTR9-PH2 Meeting Document, GTR9-1-05r1 (2011)

Correlation of Assembly Impact Responses

Correlation of ACL Injury Measures



- **No correlation between TRL legform knee shear displacement and human ACL elongation**
- **Good correlation between Flex-PLI and human ACL elongation**

Reference : Japan Automobile Standards Internationalization Center (JASIC), *Technical Discussion - Biofidelity*, 1st IG GTR9-PH2 Meeting Document, GTR9-1-05r1 (2011)

EEVC Legform Model

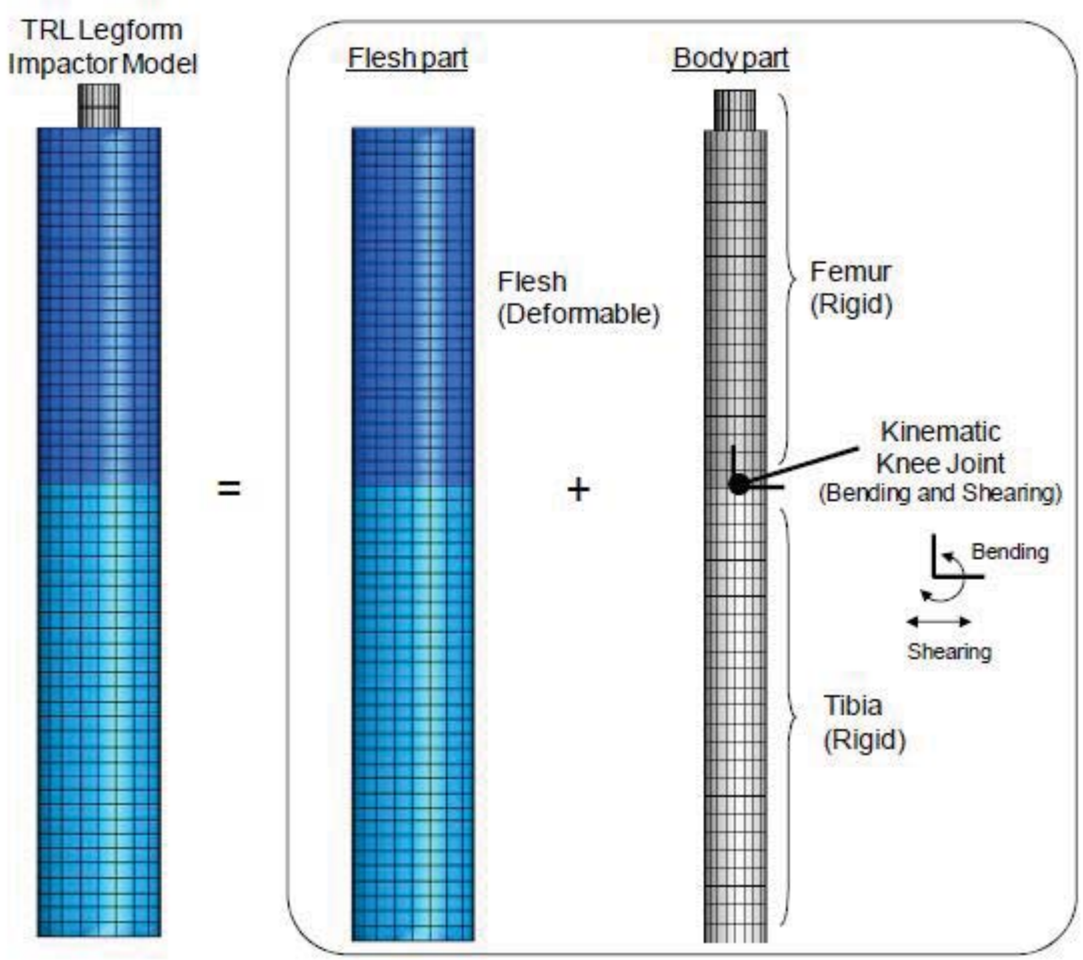


Fig. 2 - TRL Legform Impactor Model

Reference : Konosu, A. et al., *Evaluation of the Validity of the Tibia Fracture Assessment Using the Upper Tibia Acceleration Employed in the TRL Legform Impactor*, IRCOBI Conference (2009)

EEVC Legform Model

Meterial Property of Confor Foam

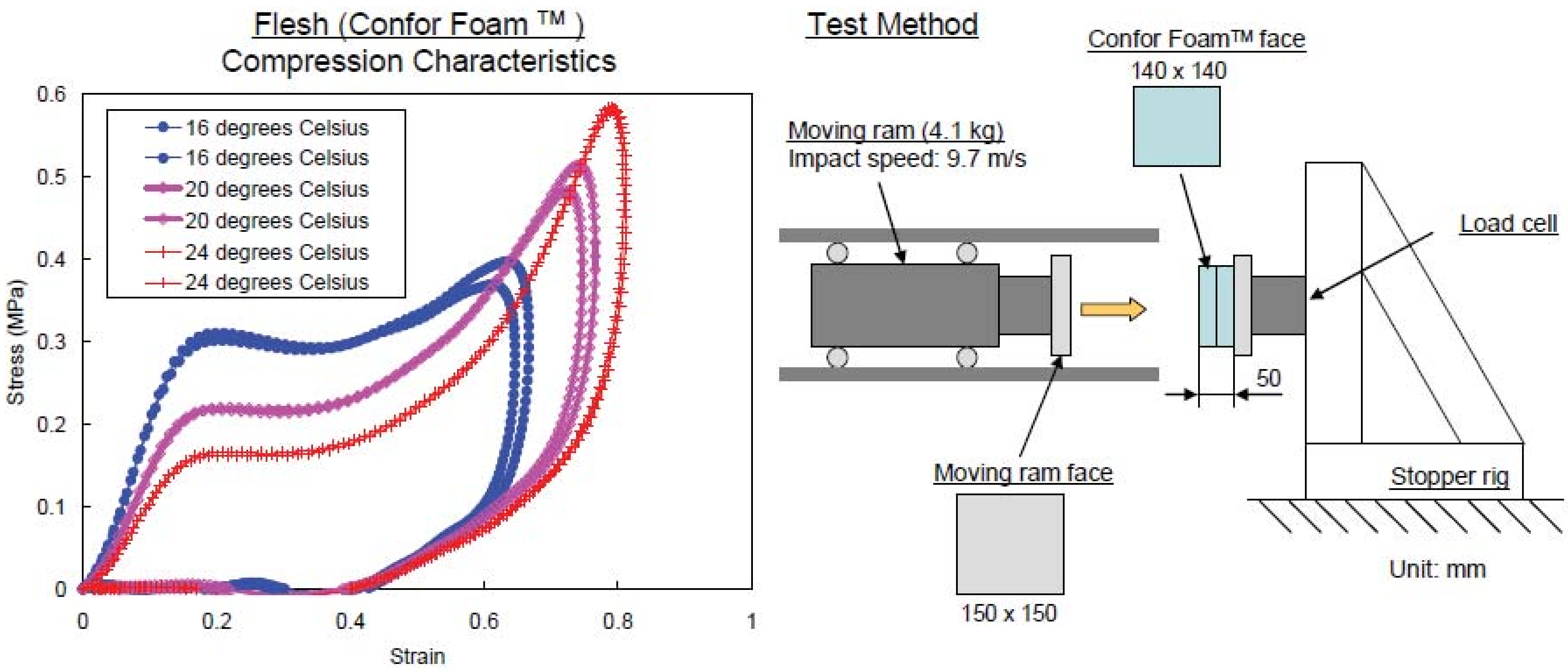


Fig. 3 - Compression Characteristics of Confor Foam ™

Stress-strain curve at 20 degrees Celsius was applied

Reference : Konosu, A. et al., *Evaluation of the Validity of the Tibia Fracture Assessment Using the Upper Tibia Acceleration Employed in the TRL Legform Impactor*, IRCOBI Conference (2009)

EEVC Legform Model

Validation of Knee Shear and Bending Characteristics against Certification Corridors

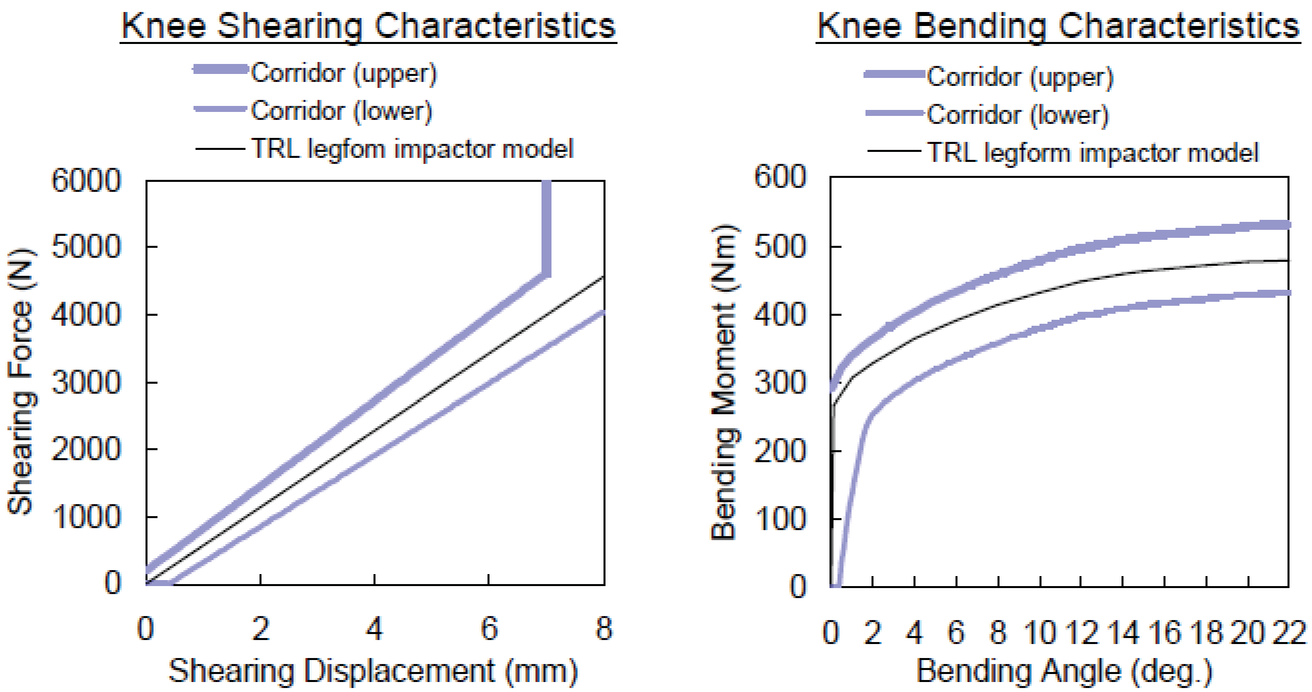


Fig. 4 - Knee Bending and Shearing Characteristics of TRL Legform Impactor Model

Reference : Konosu, A. et al., *Evaluation of the Validity of the Tibia Fracture Assessment Using the Upper Tibia Acceleration Employed in the TRL Legform Impactor*, IRCOBI Conference (2009)

EEVC Legform Model

Assembly Level Validation against Dynamic Certification Test

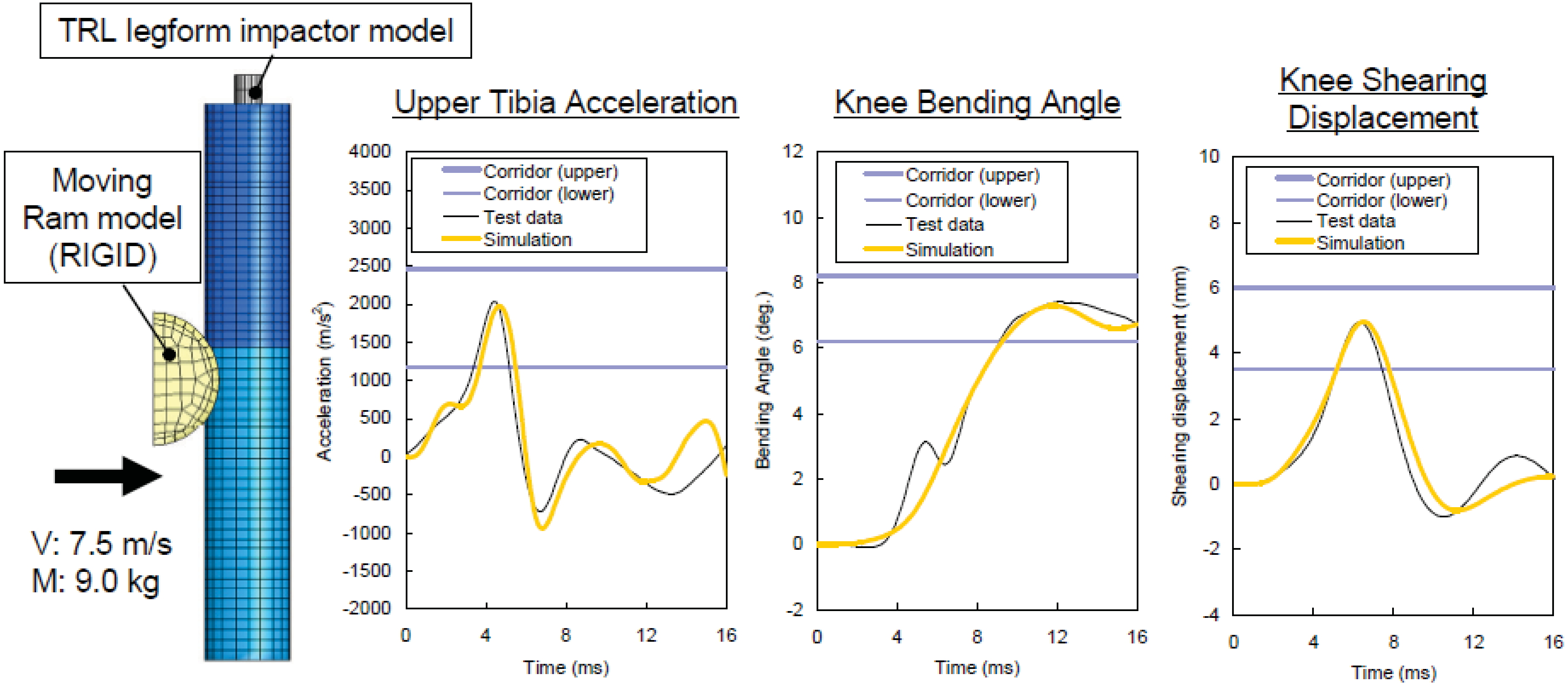


Fig. 5 - Dynamic Certification Test Simulation Results

Reference : Konosu, A. et al., *Evaluation of the Validity of the Tibia Fracture Assessment Using the Upper Tibia Acceleration Employed in the TRL Legform Impactor*, IRCOBI Conference (2009)

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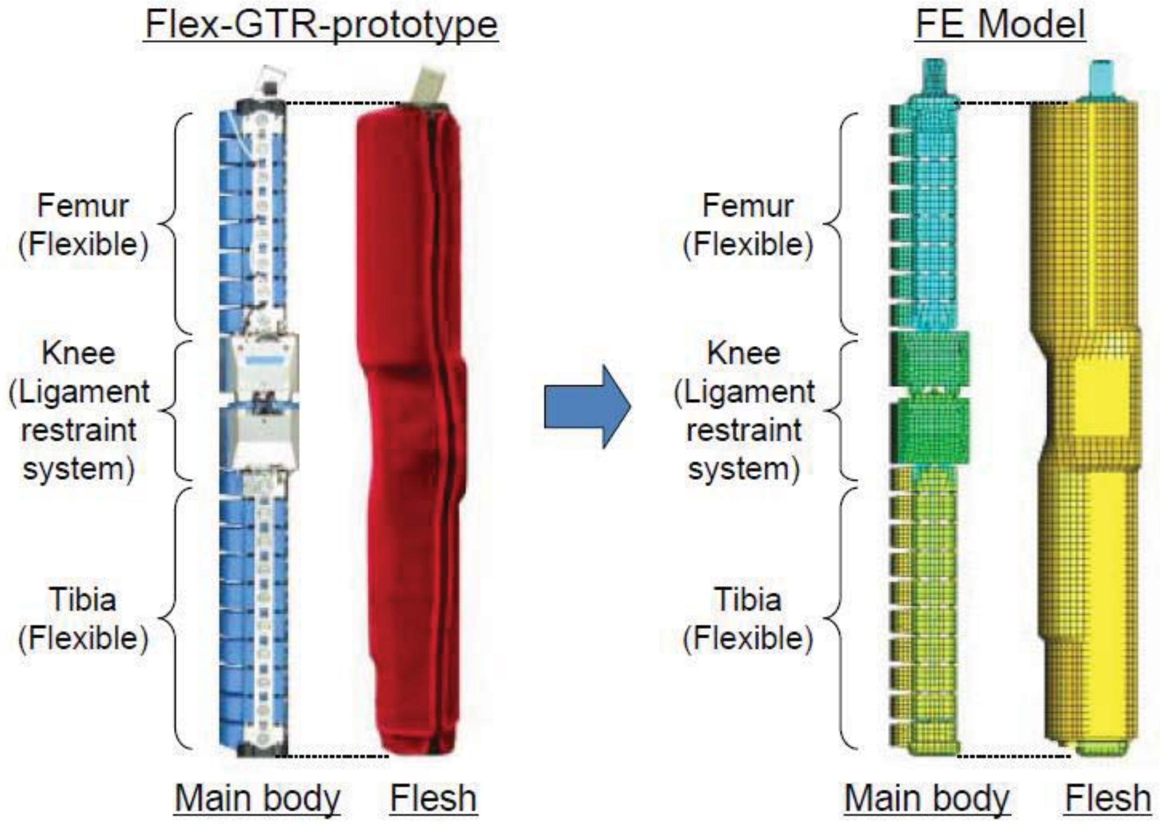
FlexPLI Model

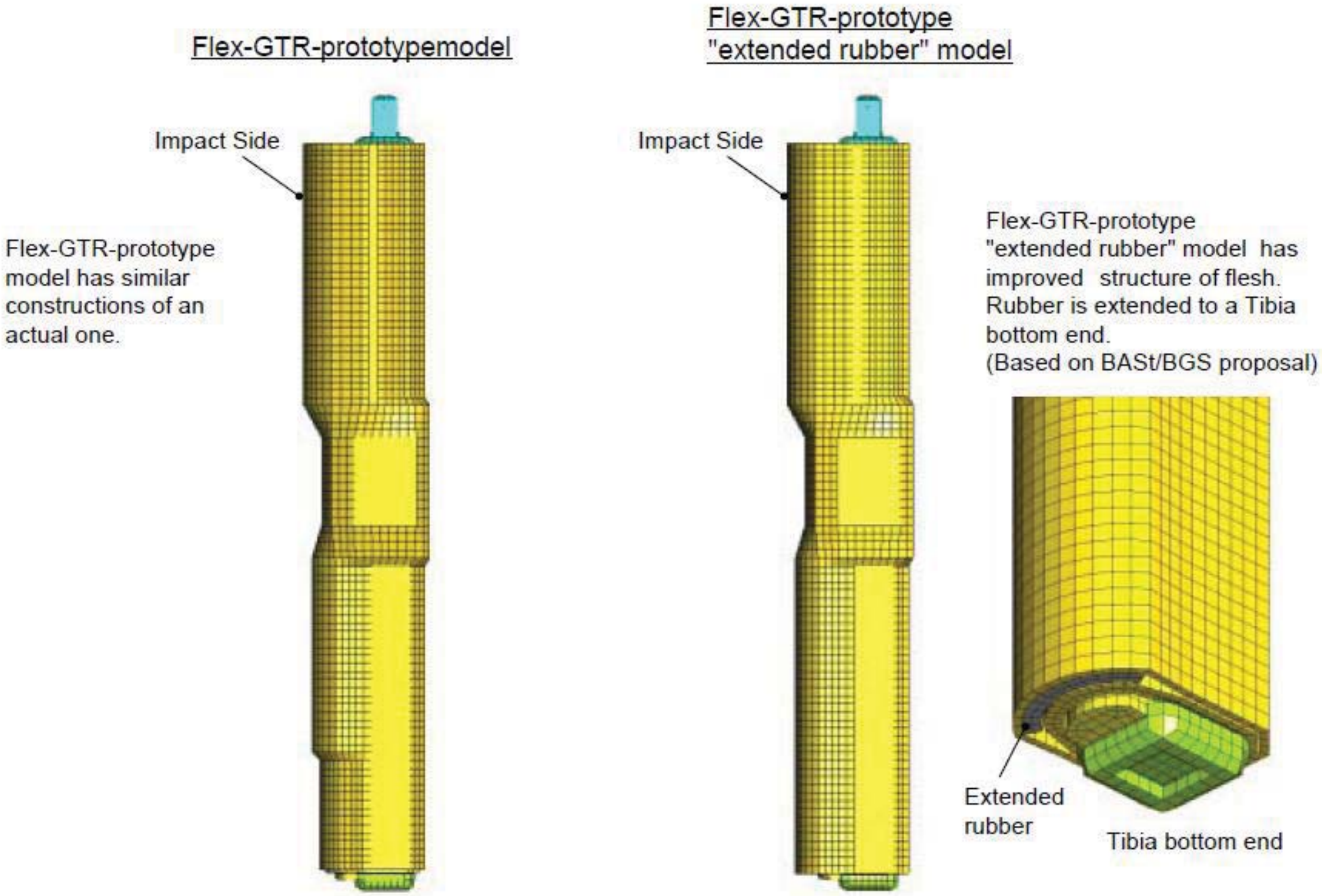
Flex-GTR-prototype and Developed FE model (Overview)



Reference : JAMA/JARI, *Development of a FE Flex-GTR-prototype model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models*, 8th Flex-TEG Meeting Document, TEG-096 (2009)

FlexPLI Model

Flex-GTR-prototype models

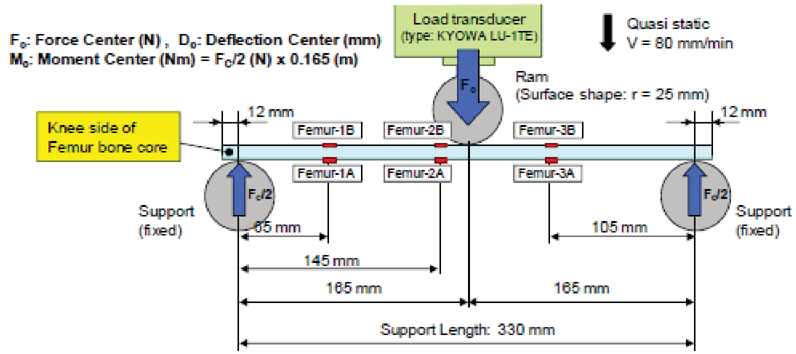


Reference : JAMA/JARI, *Development of a FE Flex-GTR-prototype model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models*, 8th Flex-TEG Meeting Document, TEG-096 (2009)

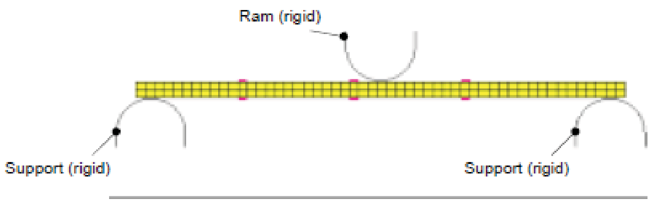
FlexPLI Model

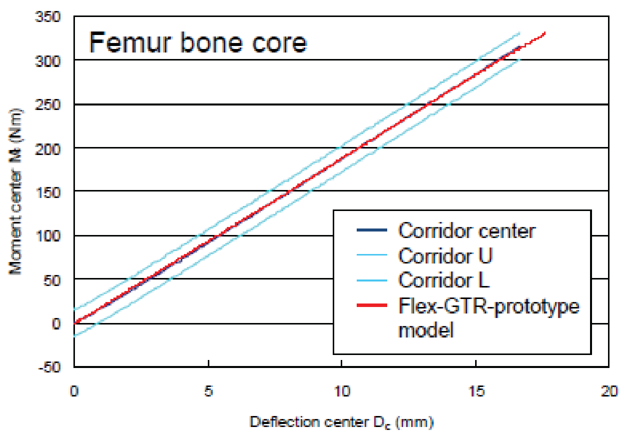
Femur bone core 3-point bending validation

Test setup for Femur bone core 3-point bending validation



Model setup for Femur bone core 3-point bending validation



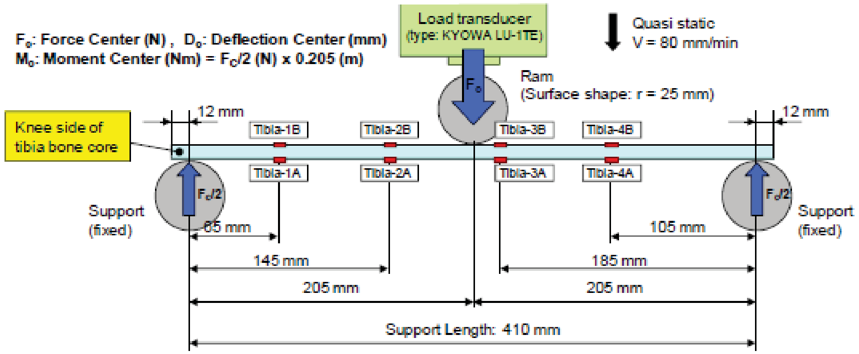


Reference : JAMA/JARI, *Development of a FE Flex-GTR-prototype model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models*, 8th Flex-TEG Meeting Document, TEG-096 (2009)

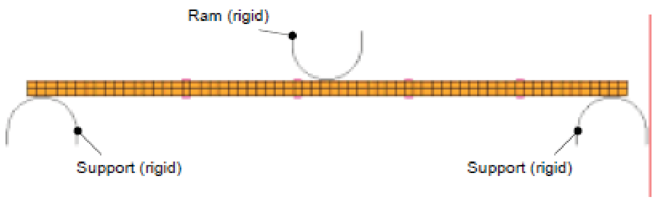
FlexPLI Model

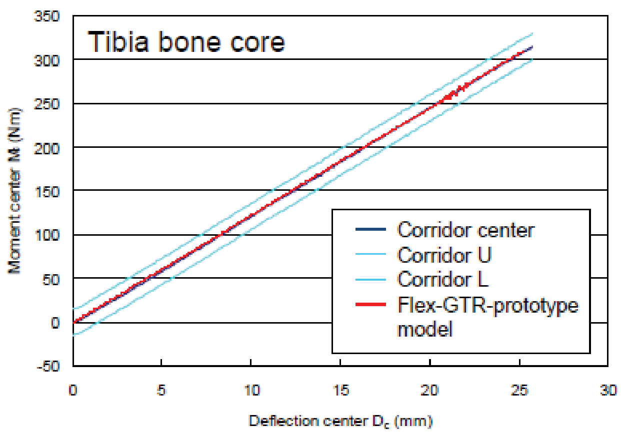
Tibia bone core 3-point bending validation

Test setup for Tibia bone core 3-point bending validation



Model setup for Tibia bone core 3-point bending validation



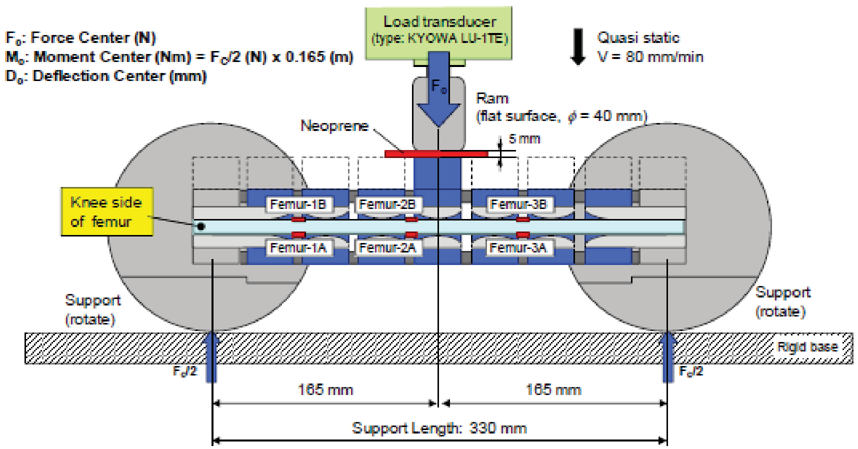


Reference : JAMA/JARI, *Development of a FE Flex-GTR-prototype model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models*, 8th Flex-TEG Meeting Document, TEG-096 (2009)

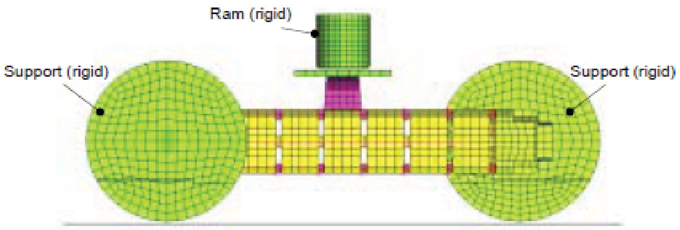
FlexPLI Model

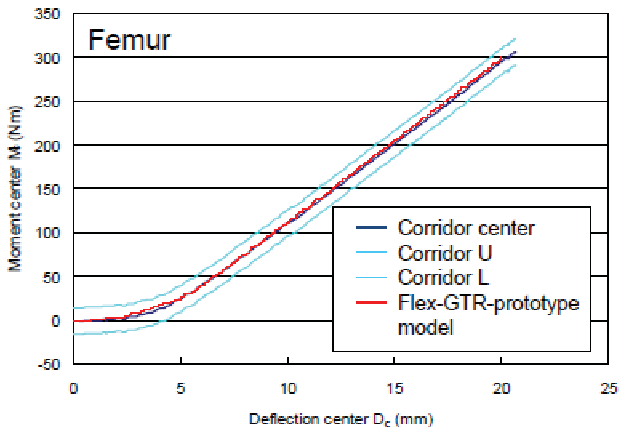
Femur 3-point bending validation

Test setup for Femur 3-point bending validation



Model setup for Femur 3-point bending validation



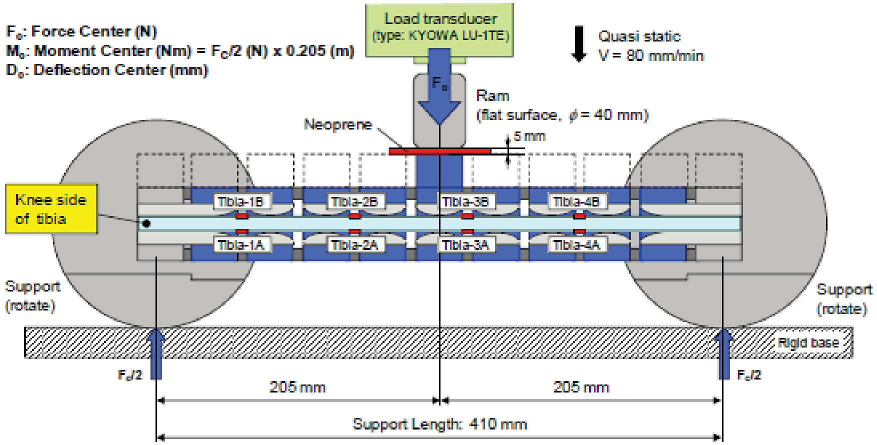


Reference : JAMA/JARI, *Development of a FE Flex-GTR-prototype model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models*, 8th Flex-TEG Meeting Document, TEG-096 (2009)

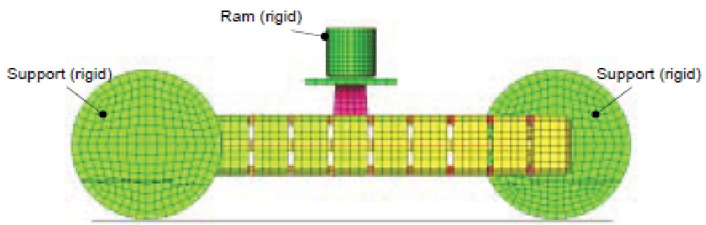
FlexPLI Model

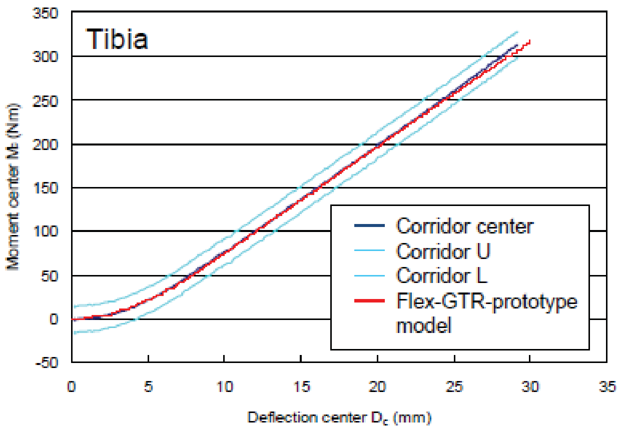
Tibia 3-point bending validation

Test setup for Tibia 3-point bending validation



Model setup for Tibia 3-point bending validation



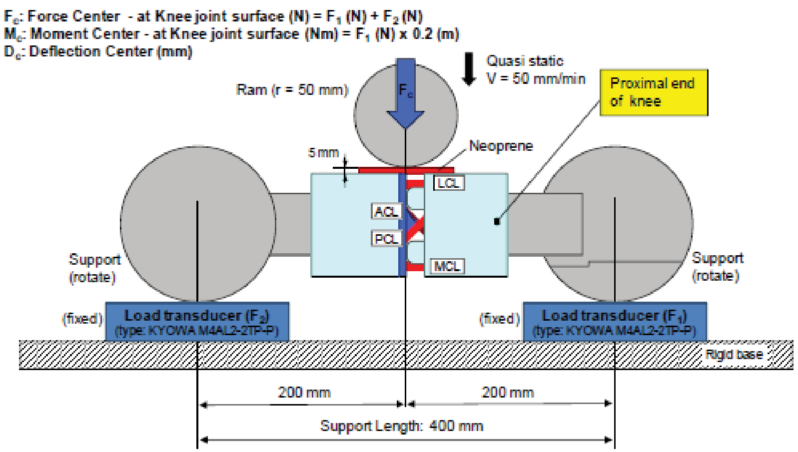


Reference : JAMA/JARI, *Development of a FE Flex-GTR-prototype model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models*, 8th Flex-TEG Meeting Document, TEG-096 (2009)

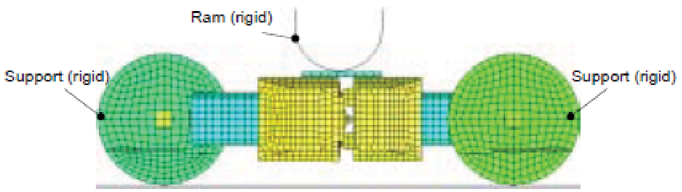
FlexPLI Model

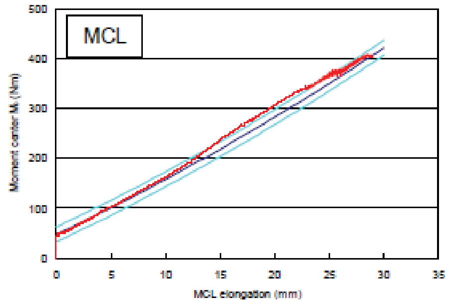
Knee 3-point bending validation

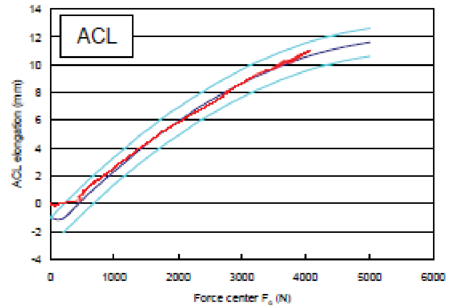
Test setup for Knee 3-point bending validation

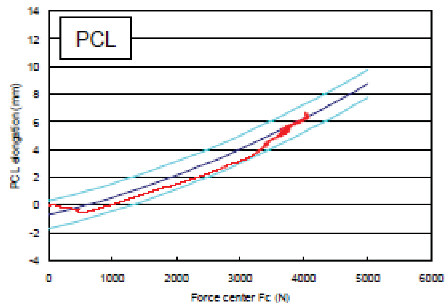


Model setup for Knee 3-point bending validation









- Corridor center
- Corridor U
- Corridor L
- Flex-GTR-prototype model

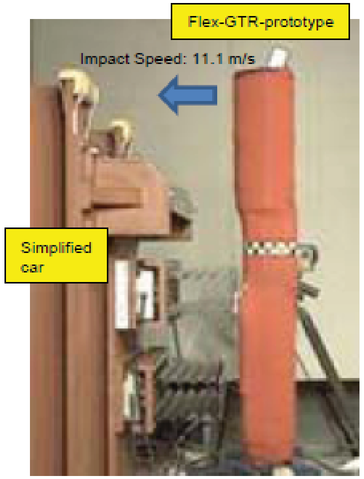
Reference : JAMA/JARI, *Development of a FE Flex-GTR-prototype model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models*, 8th Flex-TEG Meeting Document, TEG-096 (2009)

TEG-096

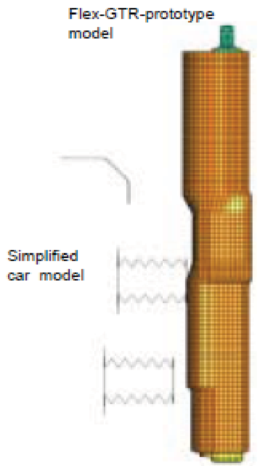
FlexPLI Model

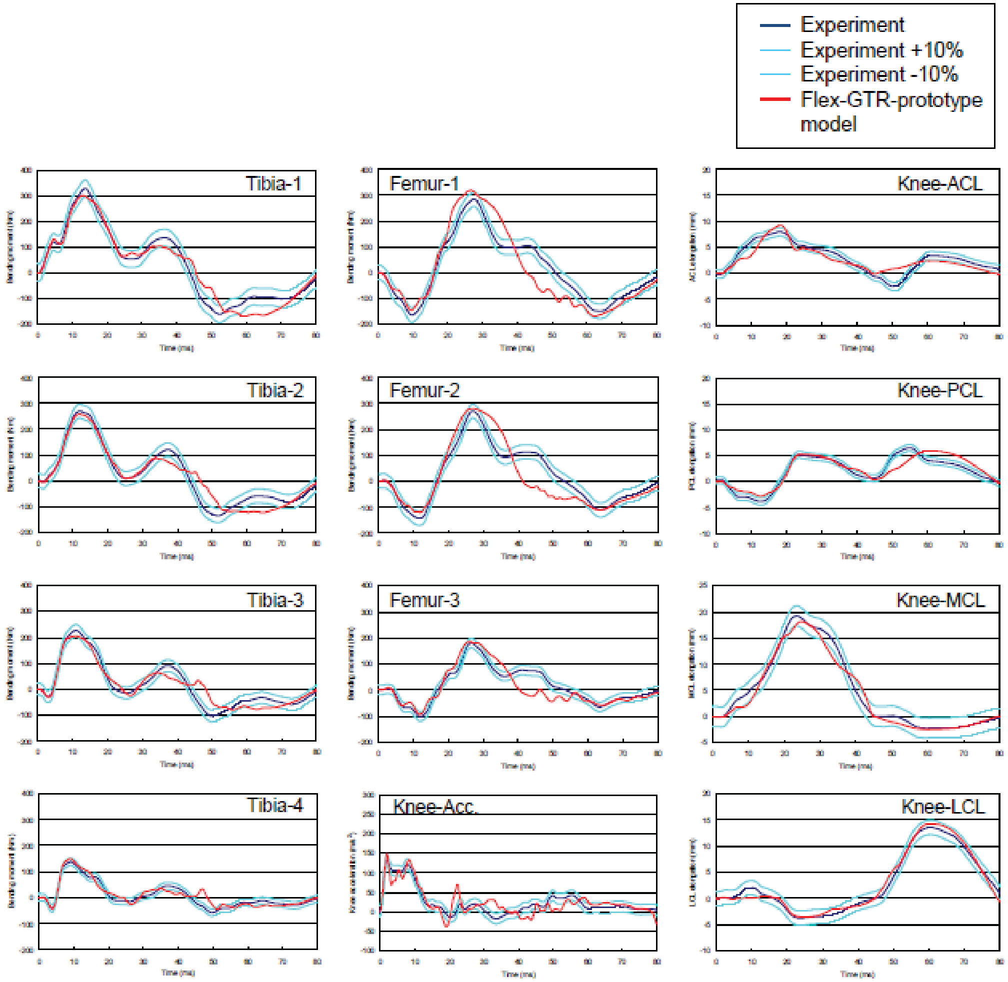
Overall validation under the Simplified Car Impact

Test setup for Simplified car validation



Model setup for Simplified car validation





Reference : JAMA/JARI, *Development of a FE Flex-GTR-prototype model and Analysis of the Correlation between the Flex-GTR-prototype and Human Lower Limb Outputs using Computer Simulation Models*, 8th Flex-TEG Meeting Document, TEG-096 (2009)

Human Model

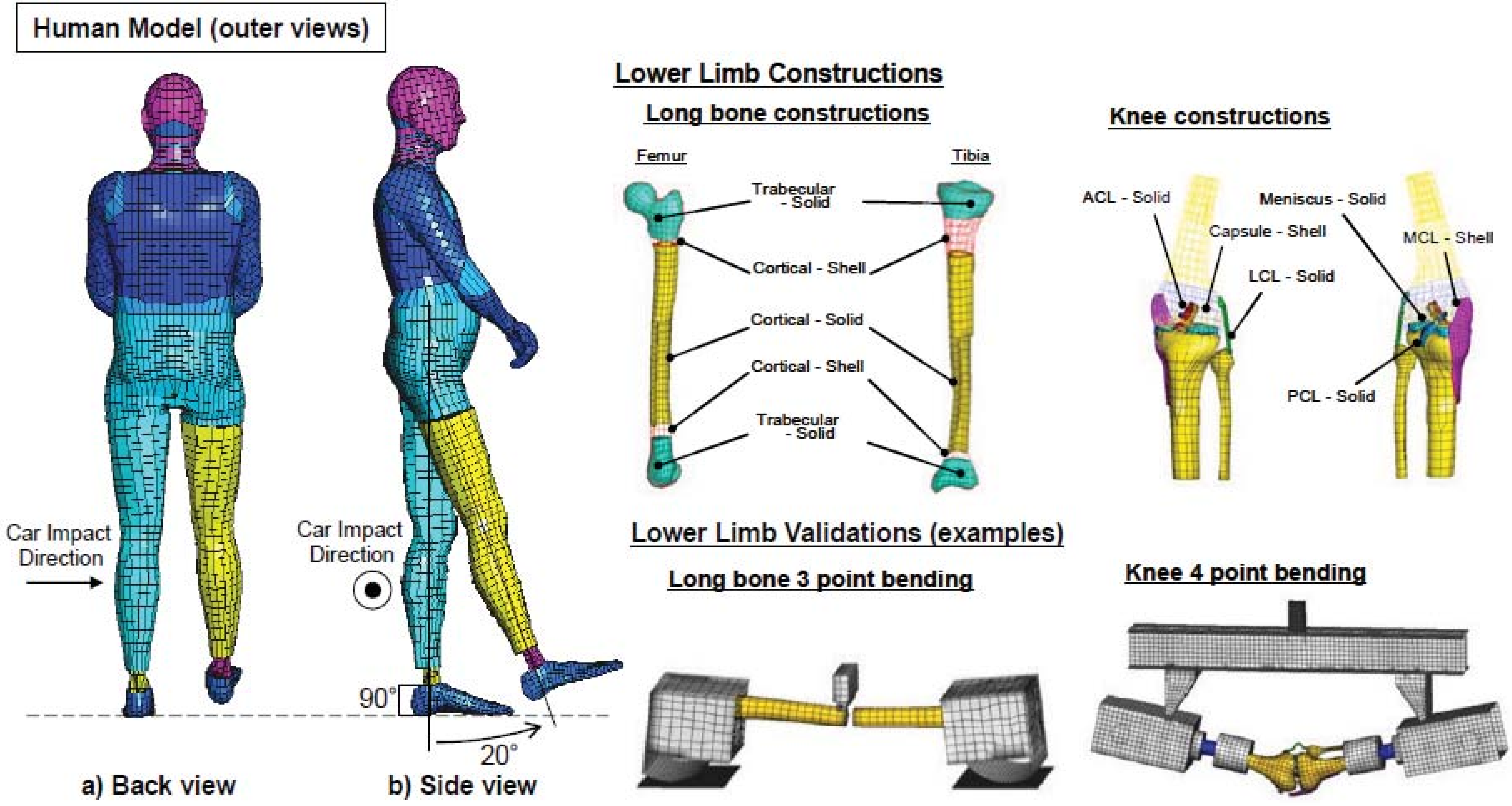


Fig. 6 - General Information for Human Model

Reference : Konosu, A. et al., *Evaluation of the Validity of the Tibia Fracture Assessment Using the Upper Tibia Acceleration Employed in the TRL Legform Impactor*, IRCOBI Conference (2009)

Human Model Validation Matrix

Body Region /Tissue		Loading Rate	Loading Configuration	Properties
Thigh	Isolated femur	• Dynamic, 1 rate	• 3-point bending • 3 loading locations	• Force-deflection • Moment-deflection
	Femur+flesh	• Dynamic, 1 rate	• 3-point bending • 2 loading locations	• Force-deflection • Moment-deflection
Knee	Isolated ligament	• Quasi-static • Dynamic, 3 rates	• ACL, PCL, MCL and LCL • Tension	• Force-deflection
	Isolated knee joint	• Dynamic, 1 rate	• 4-point bending	• Moment-angle
Leg	Isolated tibia	• Dynamic, 1 rate	• 3-point bending • 3 loading locations	• Force-deflection • Moment-deflection
	Isolated fibula	• Dynamic, 1 rate	• 3-point bending • 3 loading locations	• Force-deflection • Moment-deflection
	Tibia+fibula+flesh	• Dynamic, 1 rate	• 3-point bending • 3 loading locations	• Force-deflection • Moment-deflection
Whole body		• 40 km/h impact	• Lateral impact • 1 small sedan, 1 large SUV	• Head, T1, T8, pelvis trajectories • Pelvis and lower limb injury distribution

Human Model Validation

Isolated Femur, Tibia and Fibula

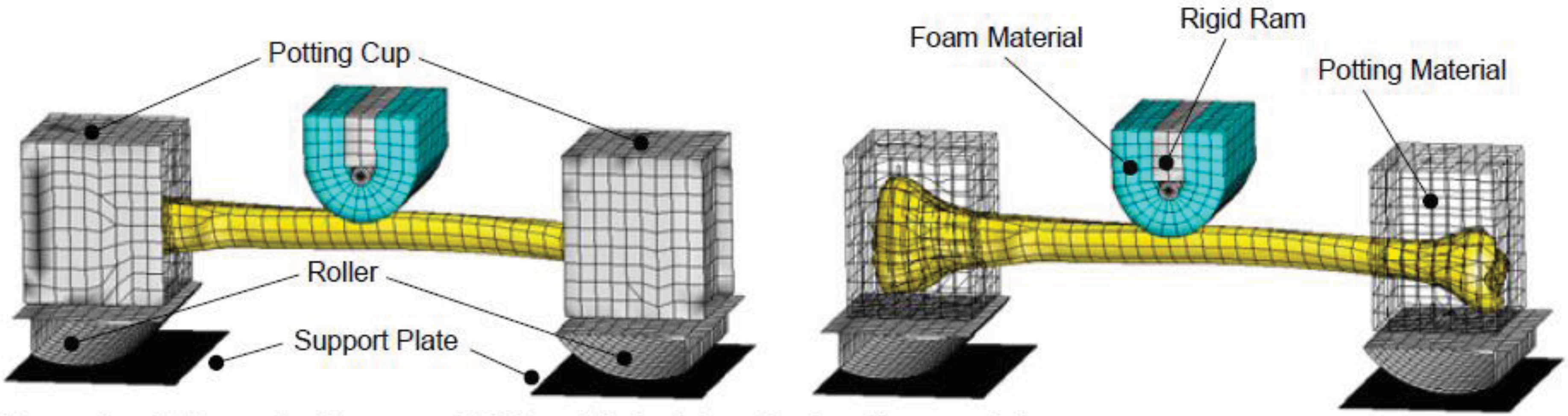


Figure 6. Schematic diagram of tibia mid-shaft 3-point bending model.

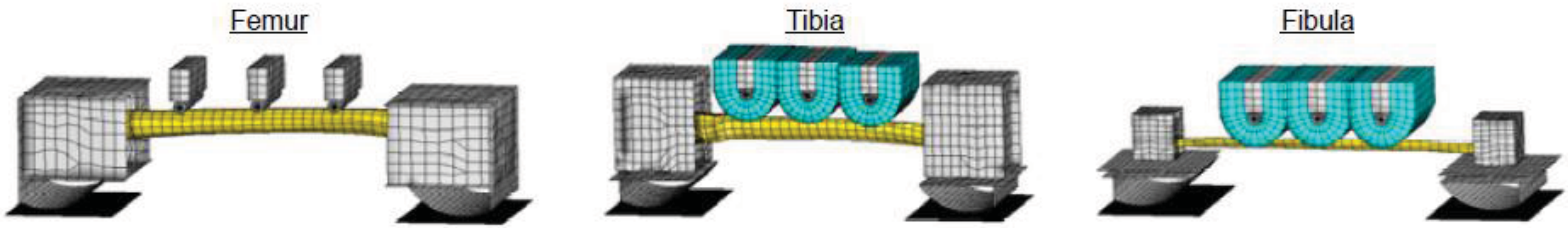


Figure 7. Model setups for 3-point bending of femur, tibia, and fibula.

Validation against dynamic 3-point bending tests at three loading locations by Kerrigan et al. (2003)

Reference : Takahashi, Y. et al., *Advanced FE Lower Limb Model for Pedestrians*, 18th ESV Conference (2003)
Kerrigan, J. et al., *Experiments for Establishing Pedestrian-Impact Lower Limb Injury Criteria*, SAE Paper #2003-01-0895 (2003)

Human Model Validation

Isolated Femur, Tibia and Fibula – Force-Deflection

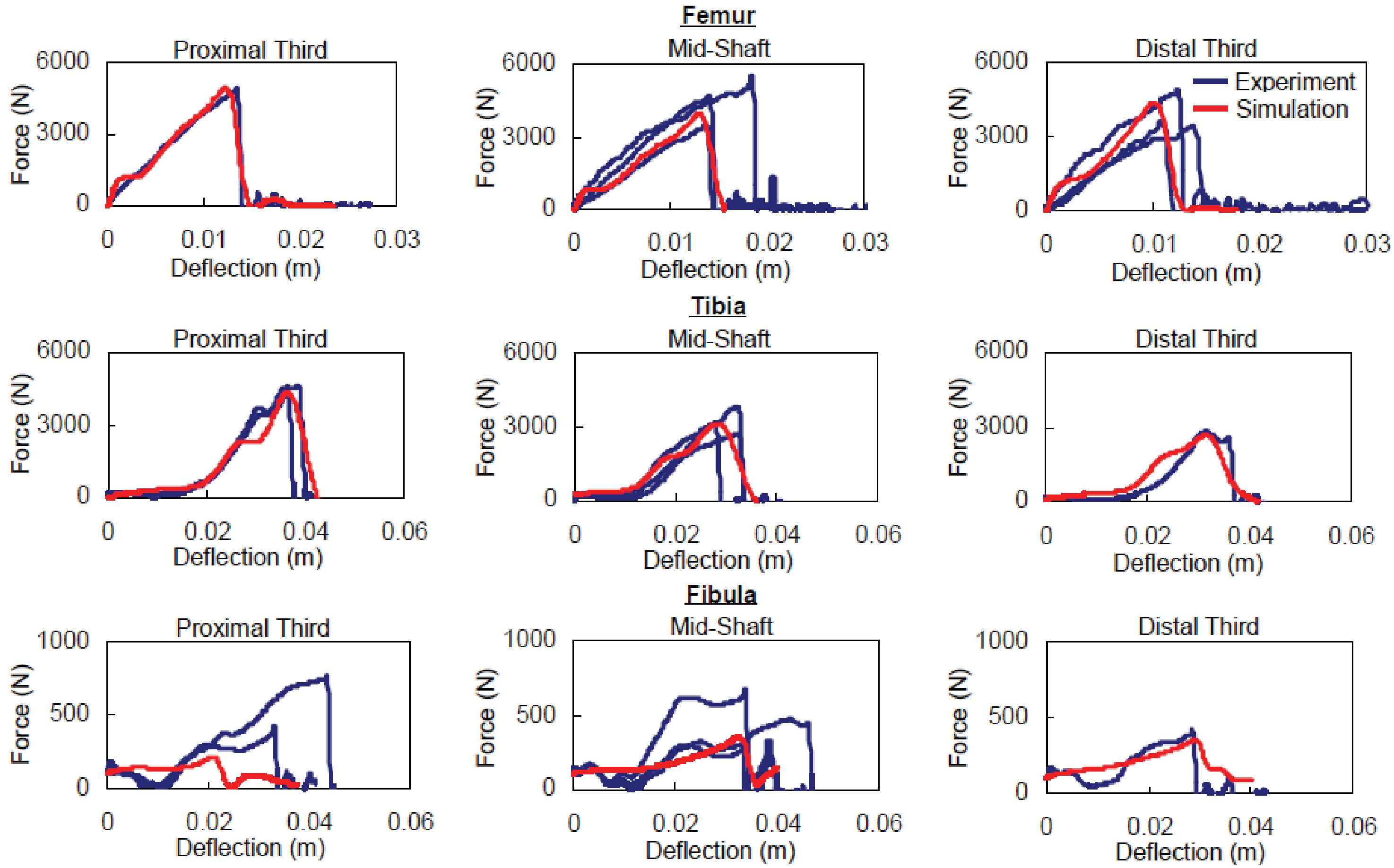


Figure 9. Comparison of force-deflection response to failure between experiment and computer simulation in dynamic 3-point bending.

Reference : Takahashi, Y. et al., *Advanced FE Lower Limb Model for Pedestrians*, 18th ESV Conference (2003)
Kerrigan, J. et al., *Experiments for Establishing Pedestrian-Impact Lower Limb Injury Criteria*, SAE Paper #2003-01-0895 (2003)

Human Model Validation

Isolated Femur, Tibia and Fibula – Moment-Deflection

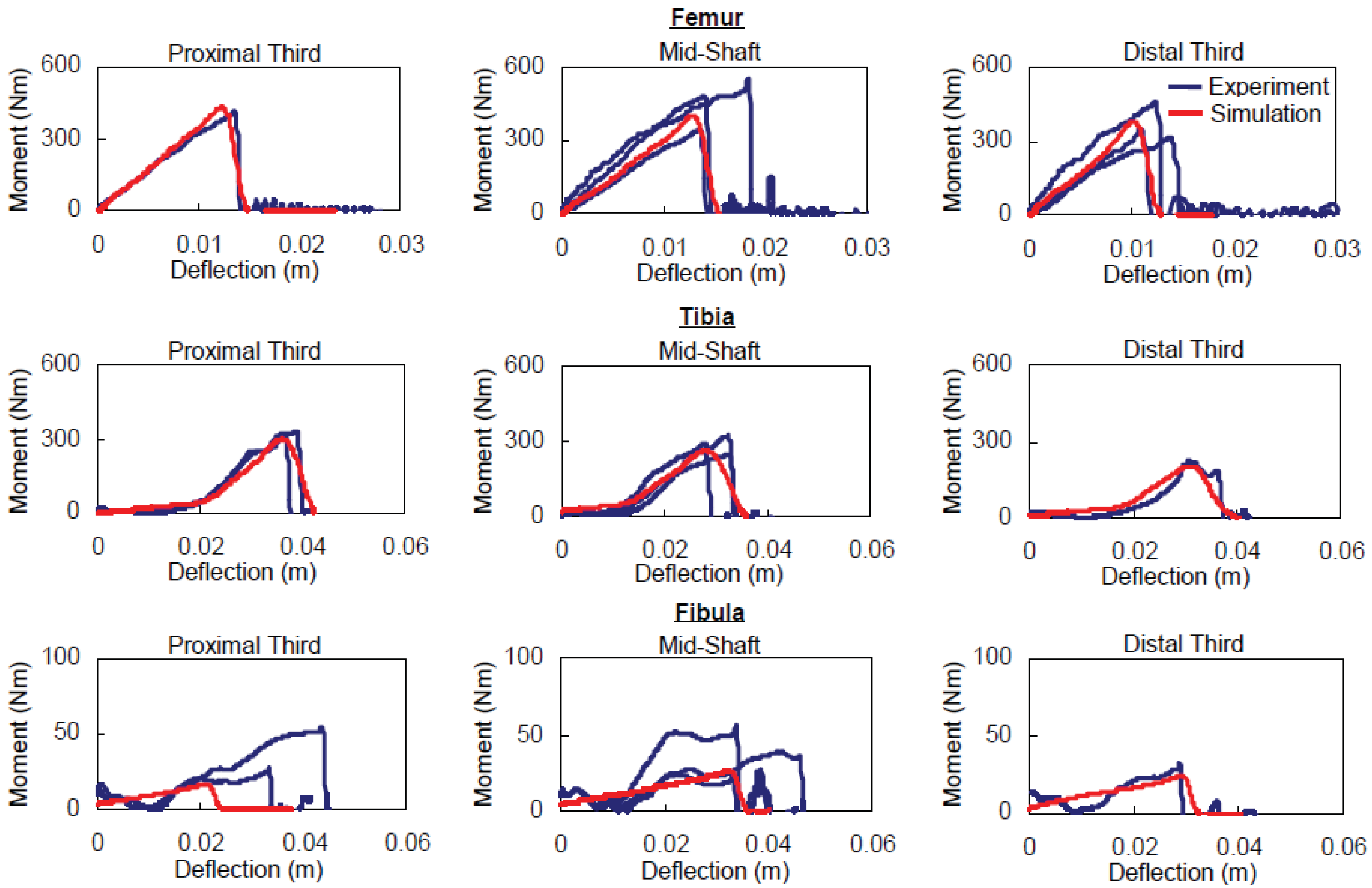


Figure 10. Comparison of moment-deflection response to failure between experiment and computer simulation in dynamic 3-point bending.

Reference : Takahashi, Y. et al., *Advanced FE Lower Limb Model for Pedestrians*, 18th ESV Conference (2003)
Kerrigan, J. et al., *Experiments for Establishing Pedestrian-Impact Lower Limb Injury Criteria*, SAE Paper #2003-01-0895 (2003)

Human Model Validation

Thigh (Femur w/Flesh) and Leg (Tibia&Fibula w/Flesh)

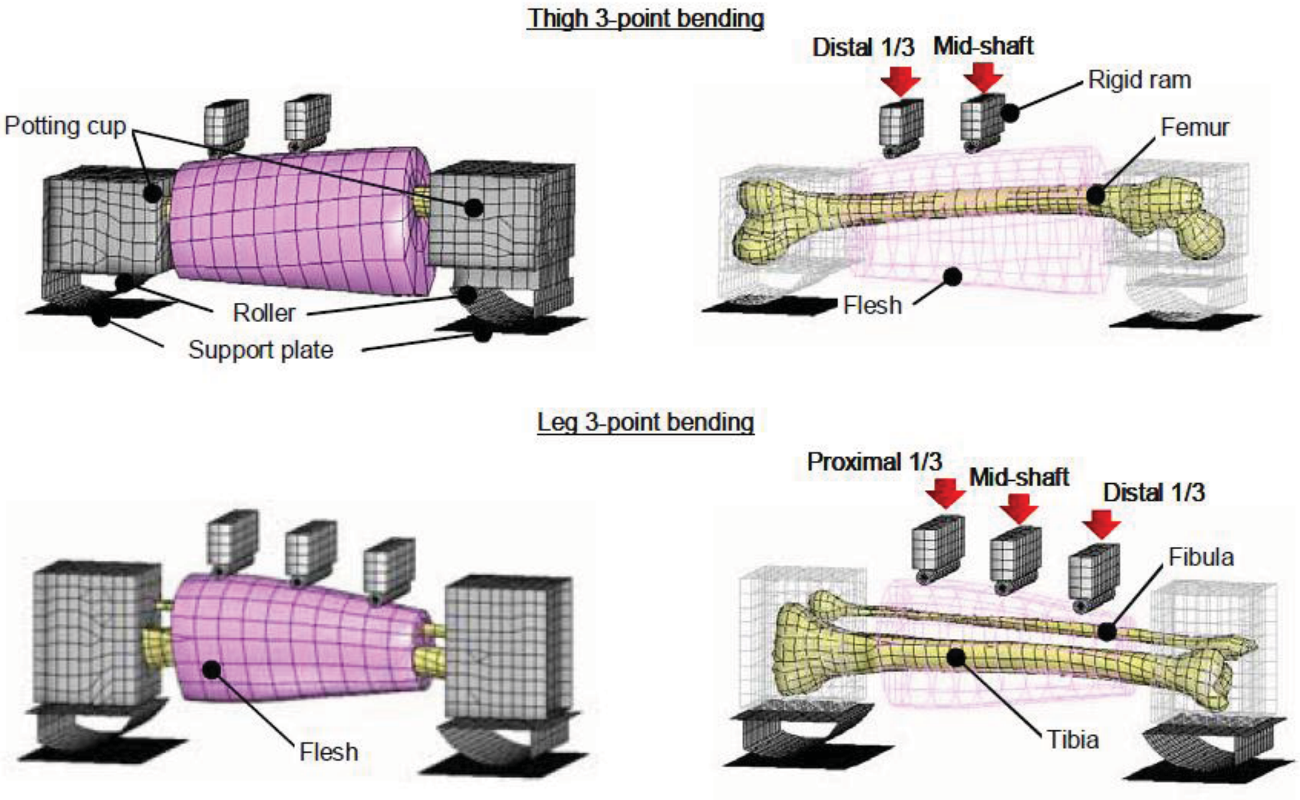


Figure 11. Model setup for 3-point bending of thigh and leg

Validation against dynamic 3-point bending tests at multiple loading locations by Ivarsson et al. (2004)

Reference : Kikuchi, Y. et al., *Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb*, SAE World Congress, Paper #2006-01-0683 (2006)
Ivarsson, J. et al., *Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities*, IRCOBI Conference (2004)

Human Model Validation

Thigh (Femur w/Flesh)

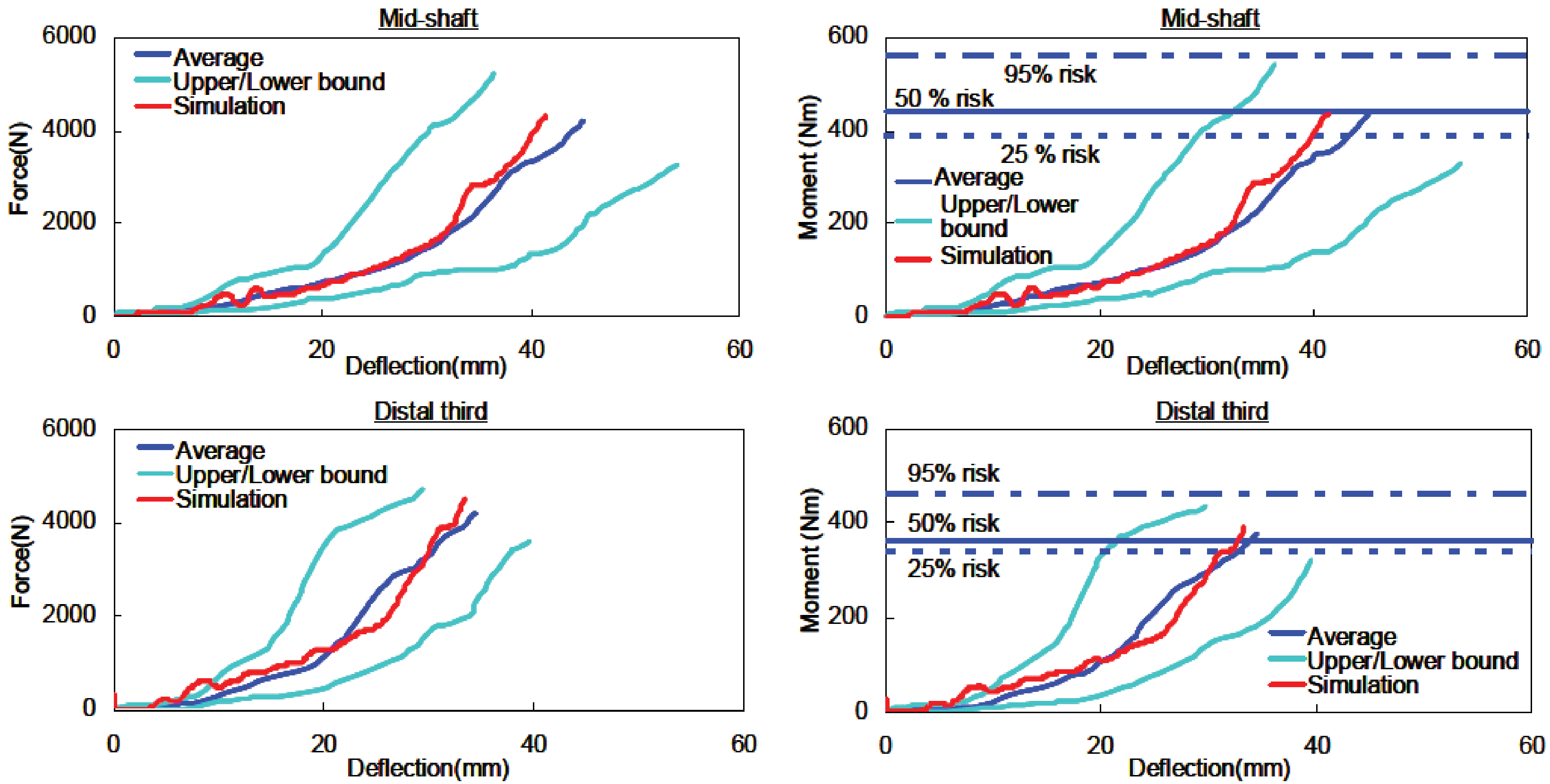


Figure 12. Comparison of force-deflection and moment-deflection responses to failure between experiment corridor and simulation in thigh 3-point bending

Reference : Kikuchi, Y. et al., *Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb*, SAE World Congress, Paper #2006-01-0683 (2006)

Ivarsson, J. et al., *Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities*, IRCOBI Conference (2004)

Human Model Validation

Leg (Tibia&Fibula w/Flesh)

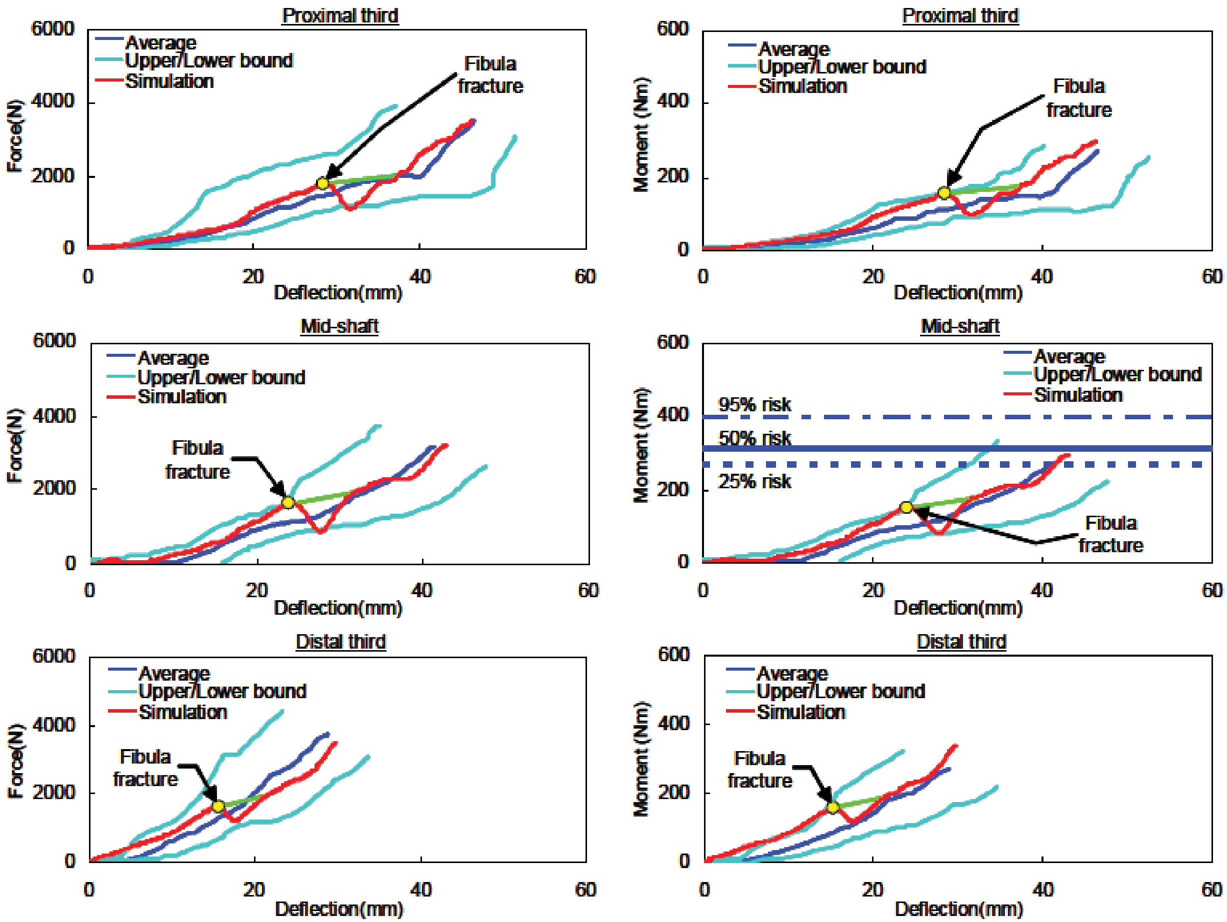


Figure 13. Comparison of force-deflection and moment-deflection responses to failure between experiment corridor and simulation in leg 3-point bending

Reference : Kikuchi, Y. et al., *Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb*, SAE World Congress, Paper #2006-01-0683 (2006)

Ivarsson, J. et al., *Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities*, IRCOBI Conference (2004)

Human Model Validation

Isolated Knee Ligaments – Takahashi et al. (2003)

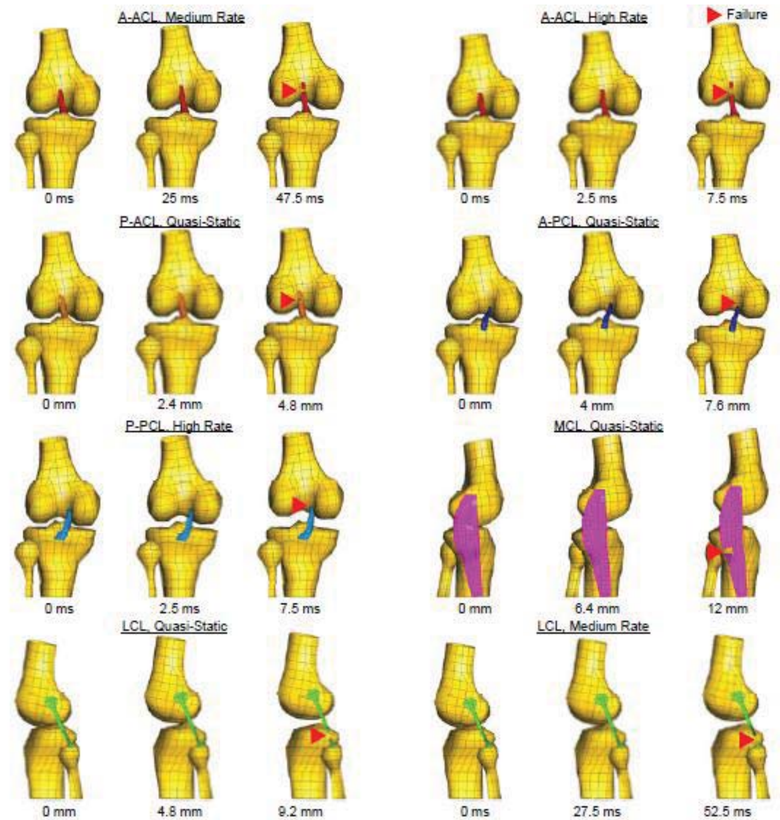


Figure 11. Time sequences of ligament tension to failure.

Table 1.
Test conditions for which test results were available

	Quasi-static (1mm/min)	Medium Rate (160mm/s)	High Rate (1600mm/s)
A-ACL		■	■
P-ACL	■		
A-PCL	■		
P-PCL			■
MCL	■		
LCL	■	■	

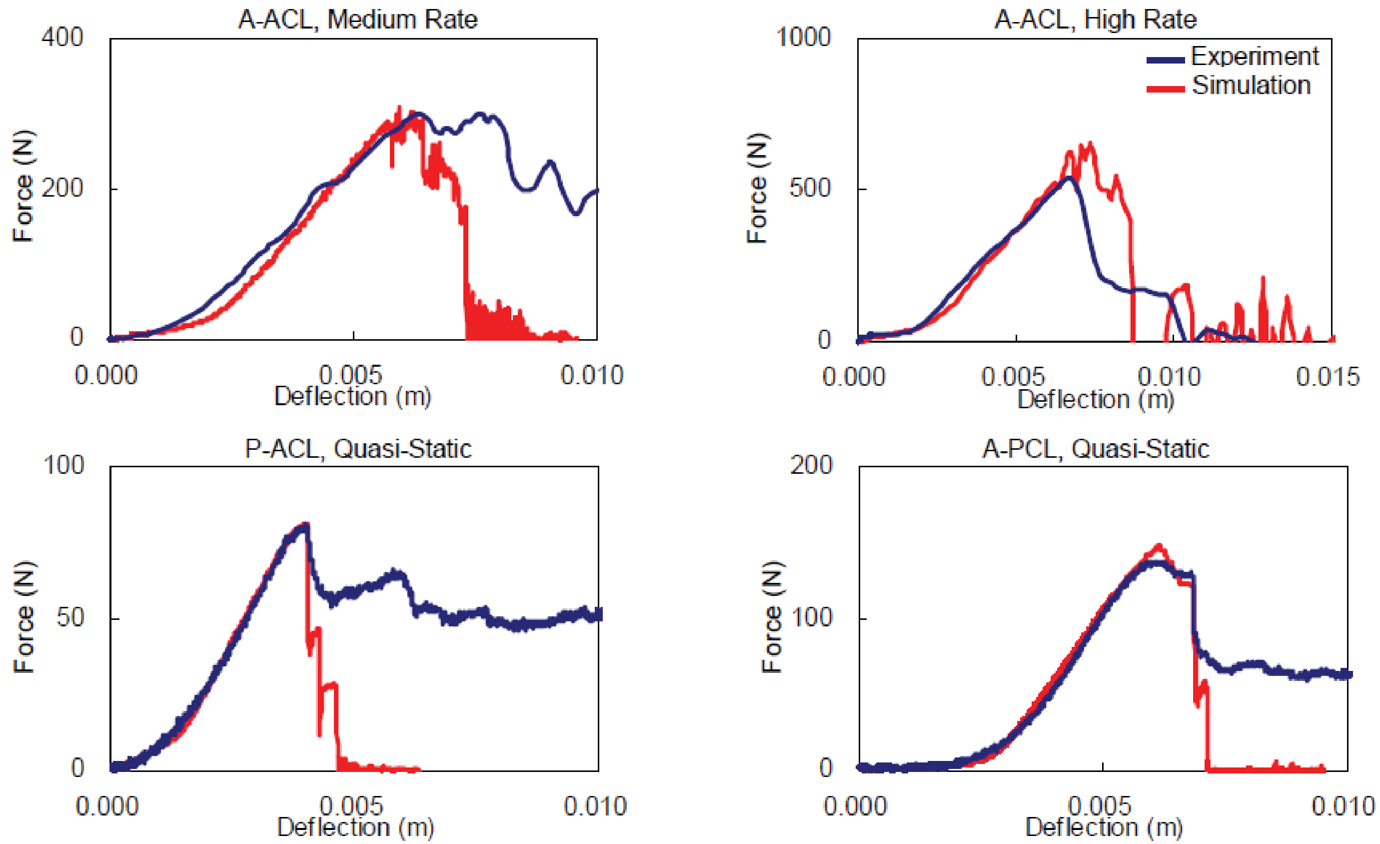
■ available

Validation against quasi-static and dynamic tensile tests by Bose et al. (2004)

Reference : Takahashi, Y. et al., *Advanced FE Lower Limb Model for Pedestrians*, 18th ESV Conference (2003)
Bose, D. et al., *Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization*, International Workshop on Human Subjects for Biomechanical Research (2002)

Human Model Validation

Isolated Knee Ligaments – Takahashi et al. (2003)



Anterior and posterior bundles of ACL and PCL were individually validated

Reference : Takahashi, Y. et al., *Advanced FE Lower Limb Model for Pedestrians*, 18th ESV Conference (2003)
Bose, D. et al., *Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization*, International Workshop on Human Subjects for Biomechanical Research (2002)

Human Model Validation

Isolated Knee Ligaments – Takahashi et al. (2003)

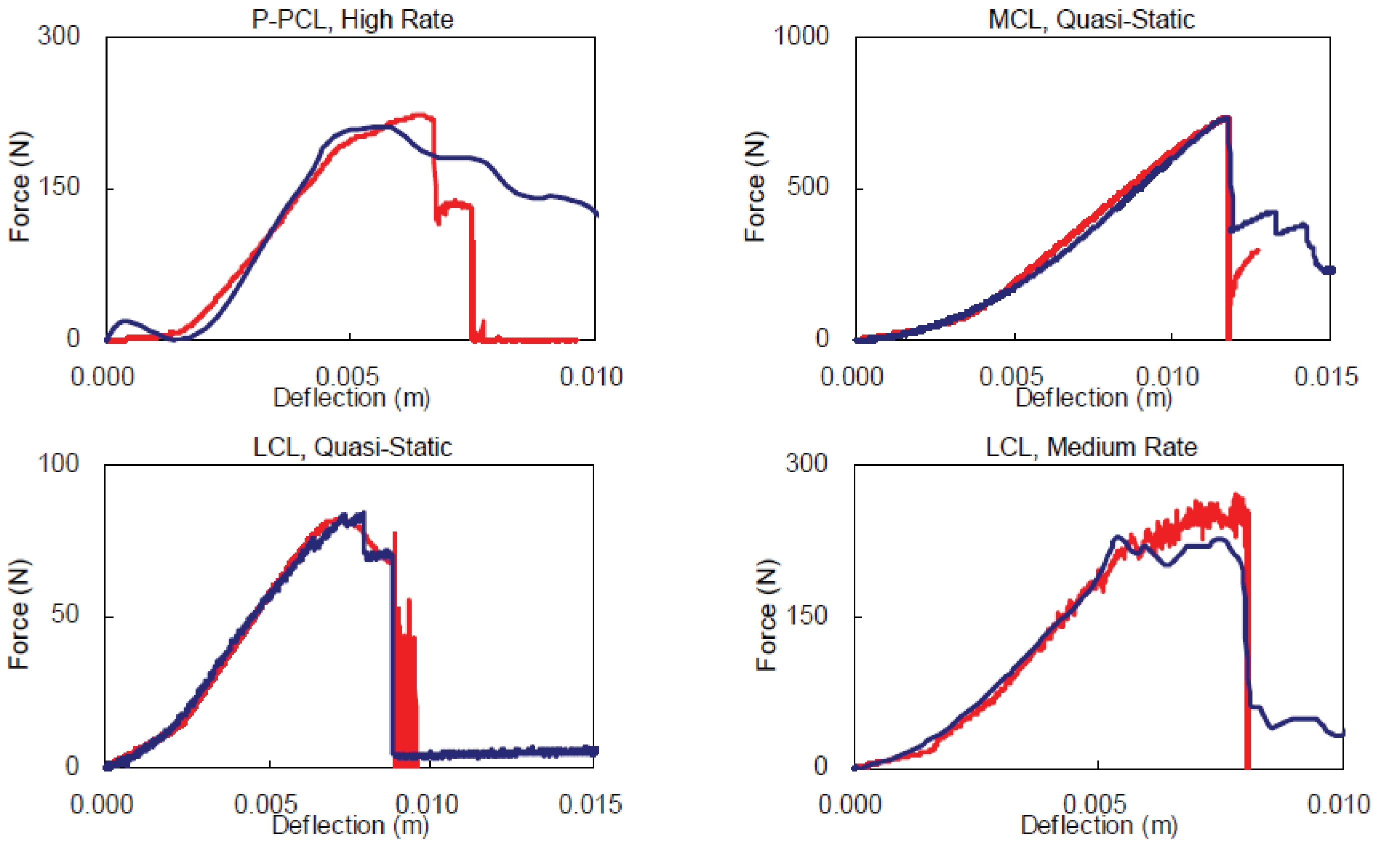


Figure 12. Comparison of force-deflection response to failure between experiment and computer simulation in quasi-static and dynamic tensile tests.

Reference : Takahashi, Y. et al., *Advanced FE Lower Limb Model for Pedestrians*, 18th ESV Conference (2003)
Bose, D. et al., *Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization*, International Workshop on Human Subjects for Biomechanical Research (2002)

Human Model Validation

Isolated Knee Ligaments – Kikuchi et al. (2006)

■:Bose et al. ▲: van Dommelen et al.

	Quasi-static (1mm/min)	Medium rate (160mm/s)	High rate (1600mm/s)
A-ACL		■	■/▲
P-ACL	■	■	▲
A-PCL	■		▲
P-PCL			■/▲
LCL	■/▲	■	▲
MCL	■/▲		▲

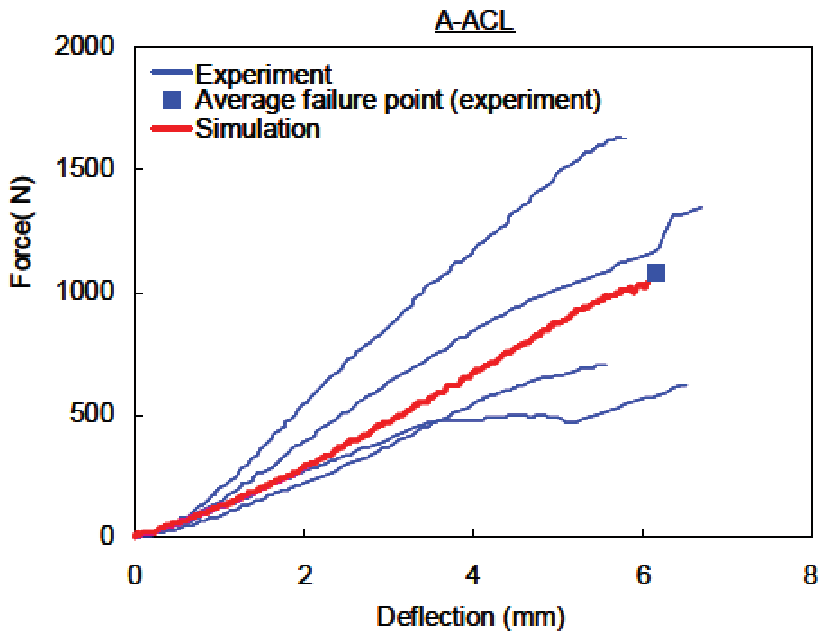
Table 2. Test conditions for which test results were available

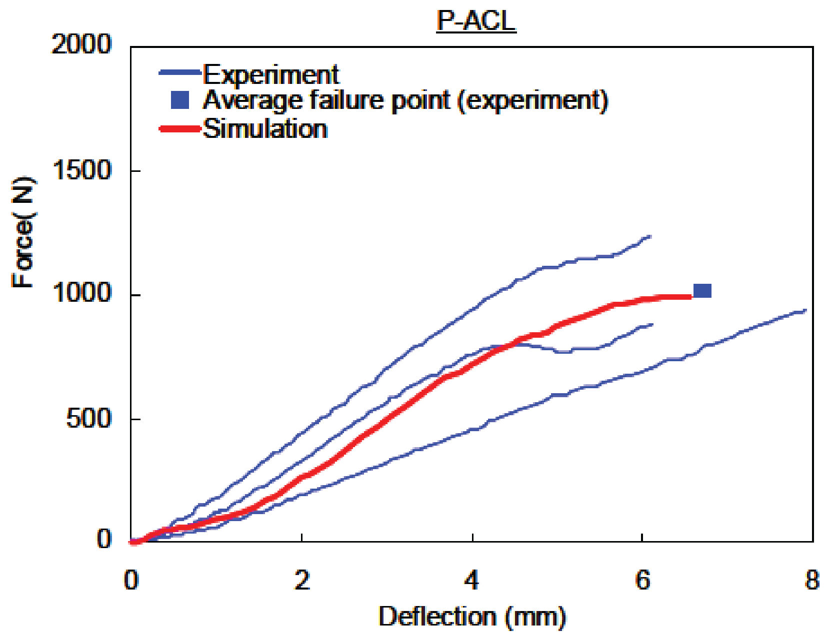
Further validation at high rate (1600 mm/s) against dynamic tensile tests by Bose et al. (2004) combined with van Dommelen et al. (2005)

Reference : Kikuchi, Y. et al., *Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb*, SAE World Congress, Paper #2006-01-0683 (2006)
Bose, D. et al., *Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization*, International Workshop on Human Subjects for Biomechanical Research (2002)
van Dommelen, J. A. W. et al., *Characterization of the Rate-Dependent Mechanical Properties and Failure of Human Knee Ligament*, SAE paper #2005-01-0293 (2005)

Human Model Validation

Isolated Knee Ligaments – Kikuchi et al. (2006)





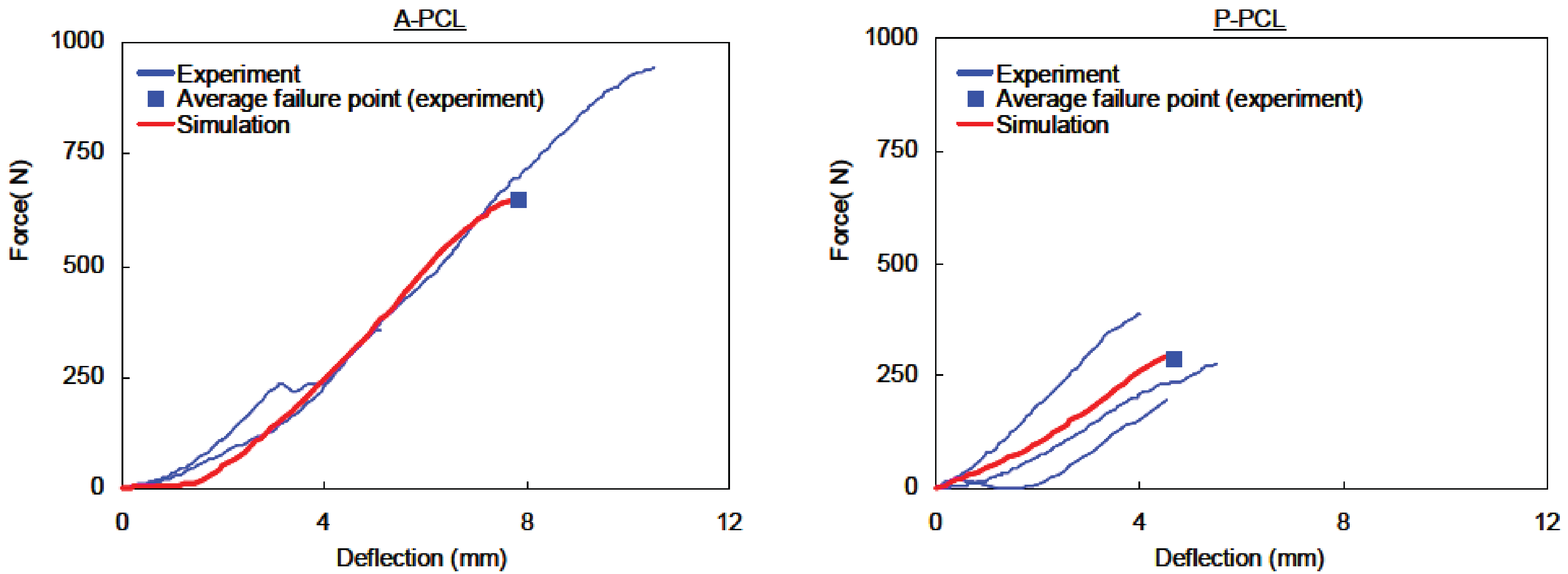
Reference : Kikuchi, Y. et al., *Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb*, SAE World Congress, Paper #2006-01-0683 (2006)

Bose, D. et al., *Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization*, International Workshop on Human Subjects for Biomechanical Research (2002)

van Dommelen, J. A. W. et al., *Characterization of the Rate-Dependent Mechanical Properties and Failure of Human Knee Ligament*, SAE paper #2005-01-0293 (2005)

Human Model Validation

Isolated Knee Ligaments – Kikuchi et al. (2006)



Reference : Kikuchi, Y. et al., *Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb*, SAE World Congress, Paper #2006-01-0683 (2006)
Bose, D. et al., *Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization*, International Workshop on Human Subjects for Biomechanical Research (2002)
van Dommelen, J. A. W. et al., *Characterization of the Rate-Dependent Mechanical Properties and Failure of Human Knee Ligament*, SAE paper #2005-01-0293 (2005)

Human Model Validation

Isolated Knee Ligaments – Kikuchi et al. (2006)

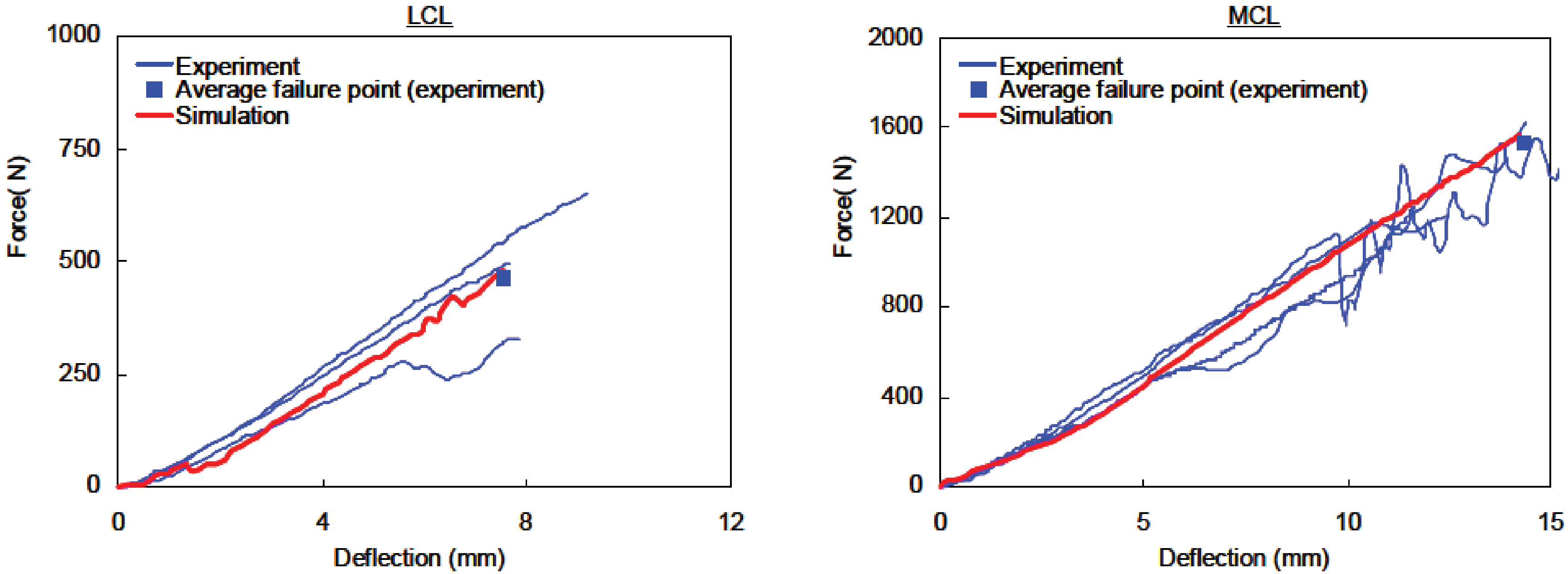


Figure 14. Comparison of force-deflection response to failure at 1600 mm/s between experiment and simulation

Reference : Kikuchi, Y. et al., *Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb*, SAE World Congress, Paper #2006-01-0683 (2006)

Bose, D. et al., *Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization*, International Workshop on Human Subjects for Biomechanical Research (2002)

van Dommelen, J. A. W. et al., *Characterization of the Rate-Dependent Mechanical Properties and Failure of Human Knee Ligament*, SAE paper #2005-01-0293 (2005)

Human Model Validation

Isolated Knee Joint

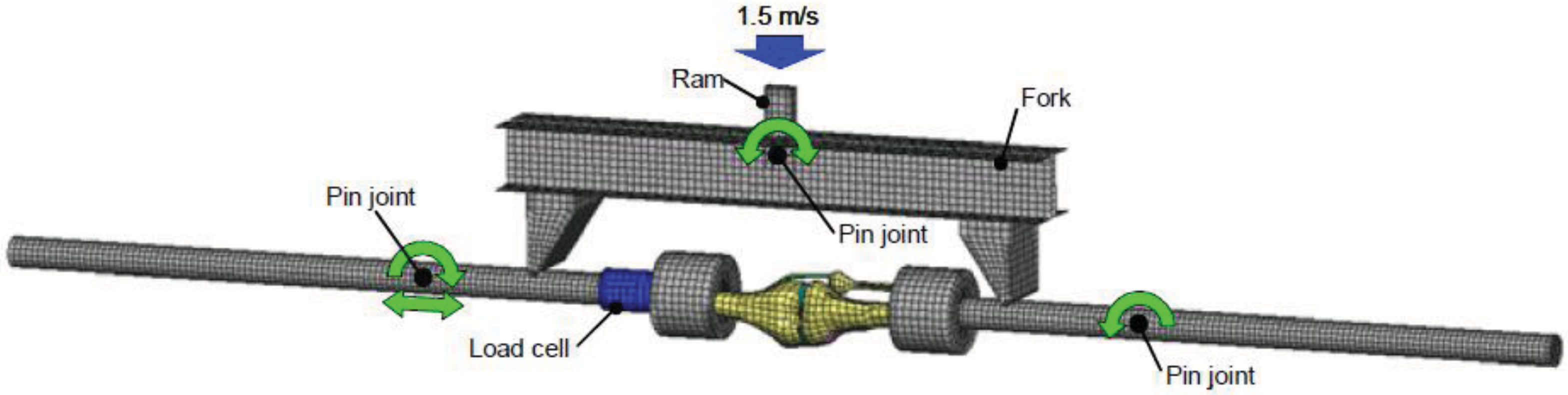


Figure 15. Model setup for knee 4-point bending

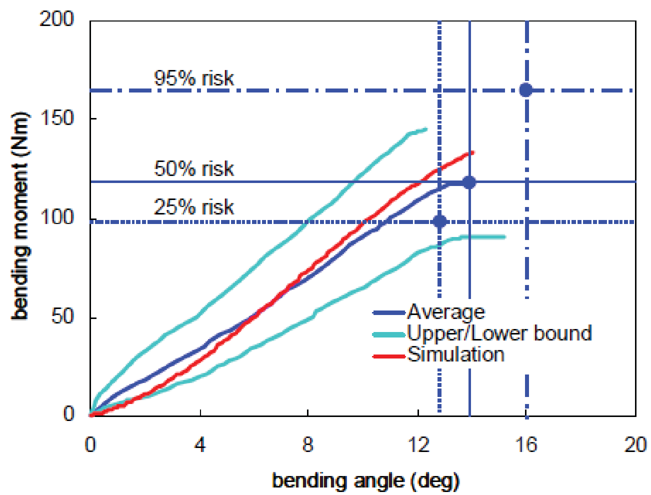


Figure 16. Comparison of bending moment-bending angle response to failure between experiment corridor and simulation in knee joint 4-point bending

Reference : Kikuchi, Y. et al., *Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb*, SAE World Congress, Paper #2006-01-0683 (2006)
Ivarsson, J. et al., *Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities*, IRCOBI Conference (2004)

Human Model Validation

Whole Body

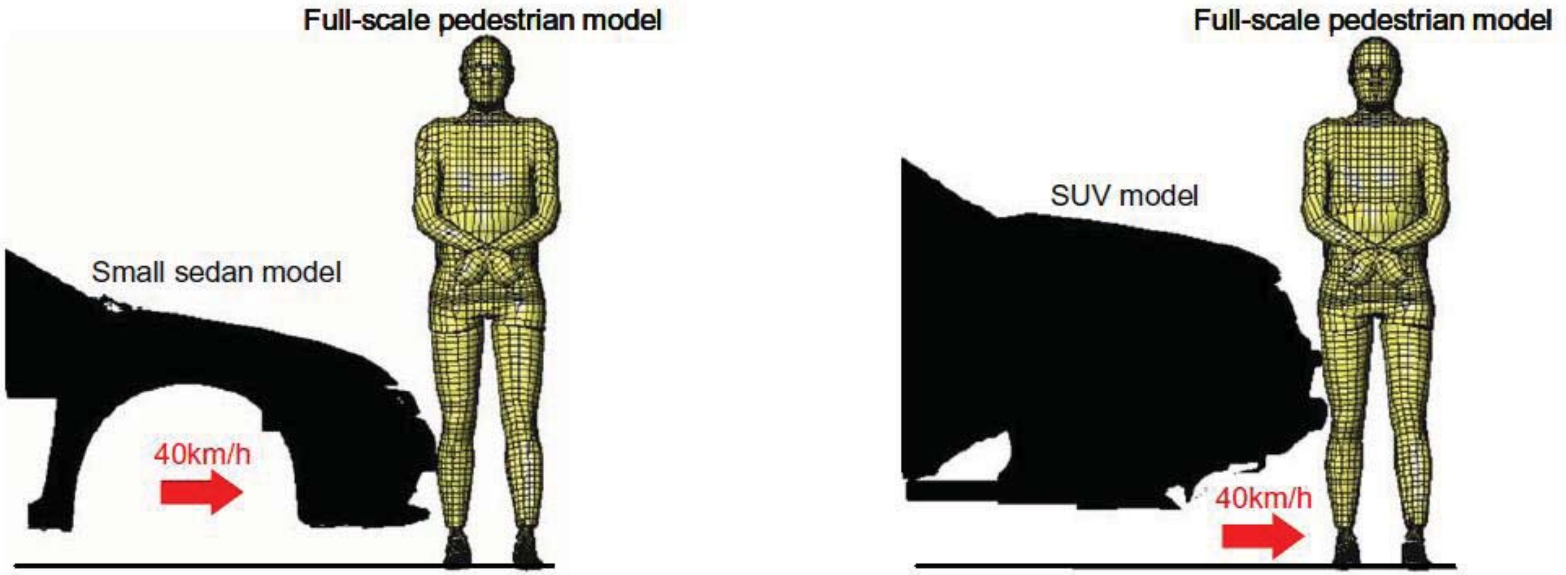


Figure 12. Model set-up for small sedan and SUV

Validation of pelvis/lower limb injury prediction and upper body kinematics for small sedan and large SUV impact tests by Kerrigan et al. (2005a, 2005b, 2008)

Reference : Kikuchi, Y. et al., *Full-Scale Validation of a Human FE Model for the Pelvis and Lower Limb of a Pedestrian*, SAE World Congress, Paper #2008-01-1243 (2008)

Kerrigan J. et al., *Kinematic Corridors for PMHS Tested in Full-Scale Pedestrian Impact Tests*, 19th ESV Conference, Paper #05-0394 (2005a)

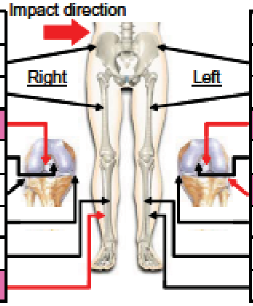
Kerrigan J. et al., *Kinematic Comparison of the Polar-II and PMHS in Pedestrian Impact Tests with a Sport-Utility Vehicle*, IRCOBI Conference (2005b)

Kerrigan J. et al., *Pedestrian Lower Extremity Response and Injury: Small Sedan vs. Large SUV*, SAE World Congress, Paper #2008-01-1245 (2008)

Human Model Validation

Whole Body – Pelvis/Lower Limb Injury Prediction

	S1	S2	S3	Frequency
Pelvis	1	0	0	33.3%
Femur	0	0	0	0.0%
ACL	0	1	1	66.7%
PCL	0	0	0	0.0%
LCL	0	0	0	0.0%
MCL	0	1	0	33.3%
Tibia	1	0	0	33.3%
Fibula	1	0	1	66.7%

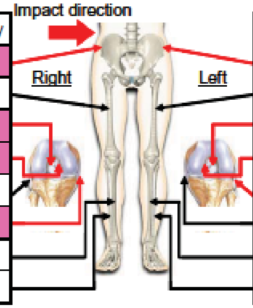


	S1	S2	S3	Frequency
Pelvis	1	0	0	33.3%
Femur	0	0	0	0.0%
ACL	1	1	1	100%
PCL	1	0	0	33.3%
LCL	1	1	1	100%
MCL	1	0	0	33.3%
Tibia	0	0	0	0.0%
Fibula	0	0	0	0.0%

Injury observed in two or more out of three cases

Figure 13. Injured pelvis and lower limb regions in car-pedestrian impact tests using small sedan for each subject (S1-3: subject number)

	U1	U2	U3	Frequency
Pelvis	1	1	0	66.7%
Femur	1	0	0	33.3%
ACL	1	1	1	100%
PCL	1	1	1	100%
LCL	0	0	0	0.0%
MCL	1	0	1	66.7%
Tibia	0	0	0	0.0%
Fibula	0	0	0	0.0%



	U1	U2	U3	Frequency
Pelvis	1	1	0	66.7%
Femur	0	0	0	0.0%
ACL	1	1	1	100%
PCL	1	1	0	66.7%
LCL	1	1	1	100%
MCL	1	0	0	33.3%
Tibia	0	0	0	0.0%
Fibula	0	0	0	0.0%

Injury observed in two or more out of three cases

Figure 15. Injured pelvis and lower limb regions in car-pedestrian impact tests using SUV for each subject (U1-3: subject number)

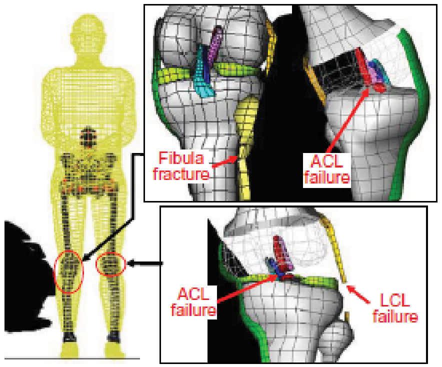


Figure 14. Injures predicted by full-scale model for small sedan

Table 2 . Comparison of injured pelvis and lower limb regions between experiment and FE prediction for small sedan impact

	Right		Left	
	Exp.	Simulation	Exp.	Simulation
Pelvis	33.3%	No injury	33.3%	No injury
Femur	0.0%	No injury	0.0%	No injury
ACL	66.7%	Failure	100%	Failure
PCL	0.0%	No injury	33.3%	No injury
LCL	0.0%	No injury	100%	Failure
MCL	33.3%	No injury	33.3%	No injury
Tibia	33.3%	No injury	0.0%	No injury
Fibula	66.7%	Fracture	0.0%	No injury

Injury observed in two or more out of three cases
Injury pedestrian by full-scale model

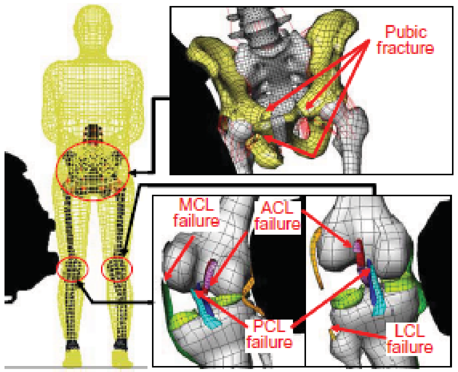


Figure 16. Injures predicated by full-scale model for SUV

Table 3 . Comparison of injured pelvis and lower limb regions between experiment and FE prediction for SUV impact

	Right		Left	
	Exp.	Simulation	Exp.	Simulation
Pelvis	66.7%	Fracture	66.7%	Failure
Femur	33.3%	No injury	0.0%	No injury
ACL	100%	Failure	100%	Failure
PCL	100%	Failure	66.7%	Failure
LCL	33.3%	No injury	100%	Failure
MCL	66.7%	Failure	33.3%	No injury
Tibia	0.0%	No injury	0.0%	No injury
Fibula	0.0%	No injury	0.0%	No injury

Injury observed in two or more out of three cases
Injury predicted by full-scale model

Reference : Kikuchi, Y. et al., *Full-Scale Validation of a Human FE Model for the Pelvis and Lower Limb of a Pedestrian*, SAE World Congress, Paper #2008-01-1243 (2008)

Kerrigan J. et al., *Kinematic Corridors for PMHS Tested in Full-Scale Pedestrian Impact Tests*, 19th ESV Conference, Paper #05-0394 (2005a)

Kerrigan J. et al., *Kinematic Comparison of the Polar-II and PMHS in Pedestrian Impact Tests with a Sport-Utility Vehicle*, IRCOBI Conference (2005b)

Kerrigan J. et al., *Pedestrian Lower Extremity Response and Injury: Small Sedan vs. Large SUV*, SAE World Congress, Paper #2008-01-1245 (2008)

Human Model Validation

Whole Body – Upper Body Kinematics
Small Sedan

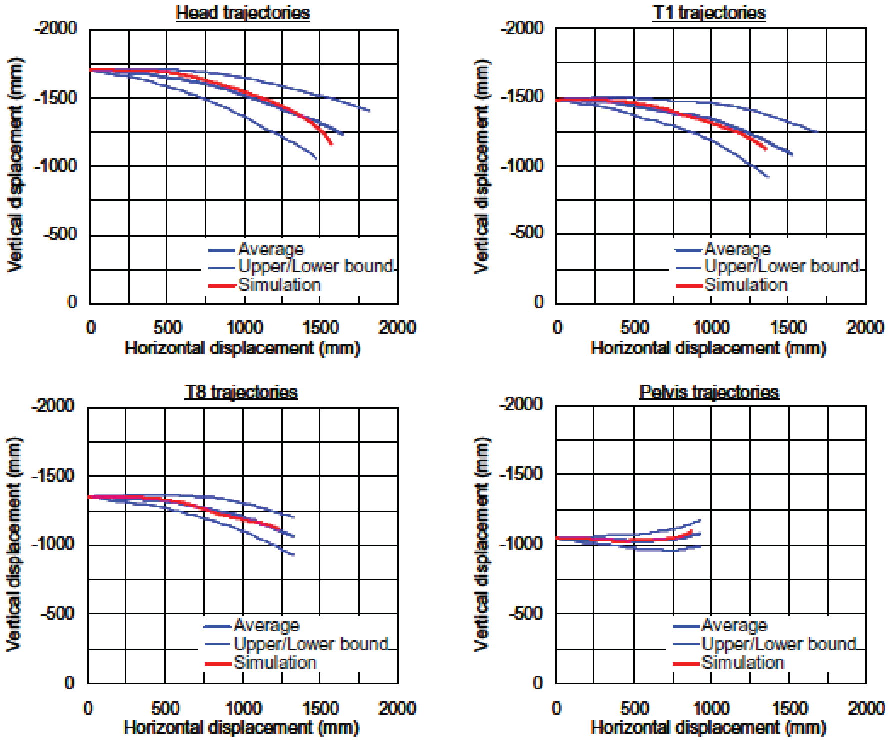


Figure 17. Comparison between the trajectory corridors for the head, T1, T8 and pelvis obtained from the experiment and the trajectories of corresponding body regions predicted by the full-scale pedestrian model for the small sedan

Reference : Kikuchi, Y. et al., *Full-Scale Validation of a Human FE Model for the Pelvis and Lower Limb of a Pedestrian*, SAE World Congress, Paper #2008-01-1243 (2008)

Kerrigan J. et al., *Kinematic Corridors for PMHS Tested in Full-Scale Pedestrian Impact Tests*, 19th ESV Conference, Paper #05-0394 (2005a)

Kerrigan J. et al., *Kinematic Comparison of the Polar-II and PMHS in Pedestrian Impact Tests with a Sport-Utility Vehicle*, IRCOBI Conference (2005b)

Kerrigan J. et al., *Pedestrian Lower Extremity Response and Injury: Small Sedan vs. Large SUV*, SAE World Congress, Paper #2008-01-1245 (2008)

Human Model Validation

Whole Body – Upper Body Kinematics

Large SUV

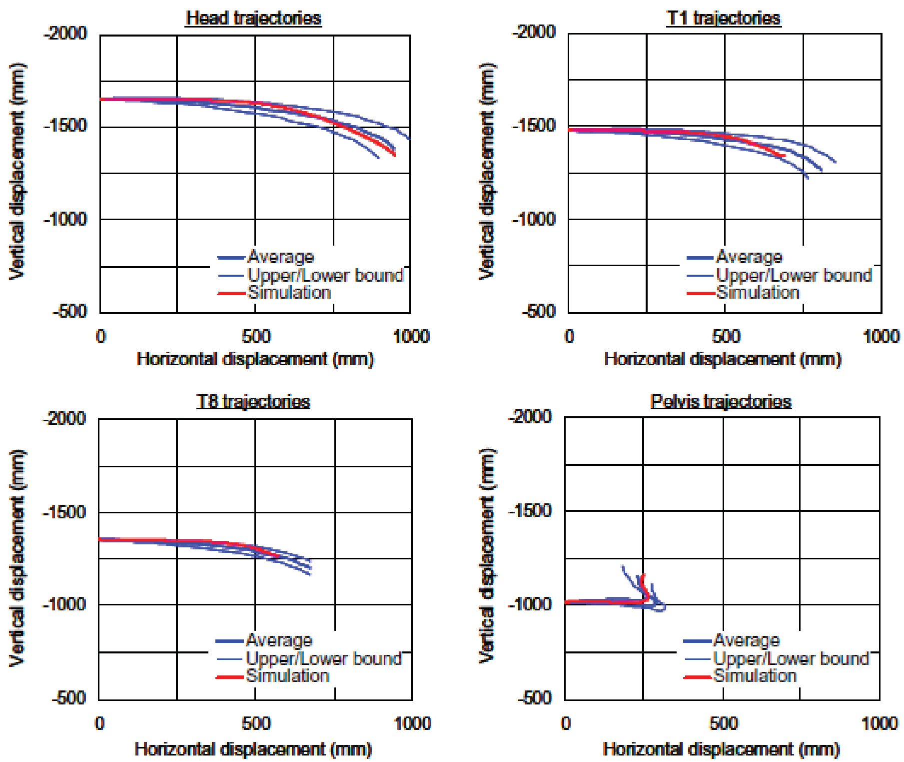


Figure 18. Comparison between the trajectory corridors for the head, T1, T8 and pelvis obtained from the experiment and the trajectories of corresponding body regions predicted by the full-scale pedestrian model for the SUV

Reference : Kikuchi, Y. et al., *Full-Scale Validation of a Human FE Model for the Pelvis and Lower Limb of a Pedestrian*, SAE World Congress, Paper #2008-01-1243 (2008)

Kerrigan J. et al., *Kinematic Corridors for PMHS Tested in Full-Scale Pedestrian Impact Tests*, 19th ESV Conference, Paper #05-0394 (2005a)

Kerrigan J. et al., *Kinematic Comparison of the Polar-II and PMHS in Pedestrian Impact Tests with a Sport-Utility Vehicle*, IRCOBI Conference (2005b)

Kerrigan J. et al., *Pedestrian Lower Extremity Response and Injury: Small Sedan vs. Large SUV*, SAE World Congress, Paper #2008-01-1245 (2008)

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- van Dommelen, J. A. W. et al., *Characterization of the Rate-Dependent Mechanical Properties and Failure of Human Knee Ligament*, SAE paper #2005-01-0293 (2005)
- Kikuchi, Y. et al., *Full-Scale Validation of a Human FE Model for the Pelvis and Lower Limb of a Pedestrian*, SAE World Congress, Paper #2008-01-1243 (2008)
- Kerrigan J. et al., *Kinematic Corridors for PMHS Tested in Full-Scale Pedestrian Impact Tests*, 19th ESV Conference, Paper #05-0394 (2005a)
- Kerrigan J. et al., *Kinematic Comparison of the Polar-II and PMHS in Pedestrian Impact Tests with a Sport-Utility Vehicle*, IRCOBI Conference (2005b)
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Thank you for your attention